HOW ARTIFICIAL INTELLIGENCE WILL CHANGE ASTRONOMY

ALL ABOUT SPACE™

ISSUE 146
AUGUST 2023

GUIDE TO THE MILKY WAY

EVERYTHING YOU NEED TO KNOW ABOUT OUR HOME GALAXY

+

MINING AN ASTEROID

FUTURISTIC SPACE TECH

NEIL DEGRASSE TYSON INTERVIEW

CLIMATE CHANGE
BEYOND EARTH

MUST-SEE
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WELCOME

ISSUE 146

SCAN HERE TO GET OUR DAILY NEWSLETTER

Did you know that the Milky Way has between 100 and 400 billion stars? How about that it has an invisible halo? This issue, we're taking a tour of our galaxy. From its spiral arms to the kinds of stars that you can find within it, this month we're offering you a guide to everything you need to know about the mammoth structure we call home. Turn to page 14 to begin your exploration!

Also this issue we have Ask Space, where our team of experts answer your questions, speak to Neil deGrasse Tyson about the multiverse and if we could be living in a hologram, our mysteries of the universe feature, a report on climate change in the Solar System and so much more. We hope you enjoy the issue.

Before I sign off, I wanted to remind you that we have some fantastic offers on a subscription to the magazine, along with a whole host of exclusive deals! Why not head over to **magazinesdirect.com** to subscribe and save or complete your collection with our collection of back issues? See you next time!

GEMMA LAVENDER
Editor

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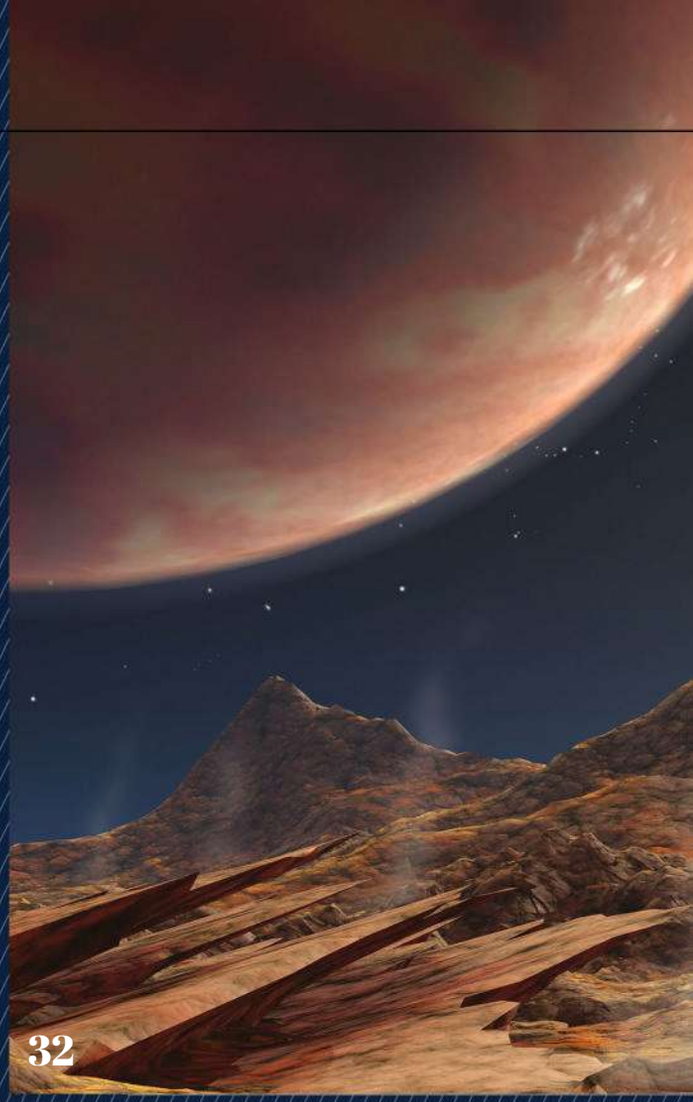

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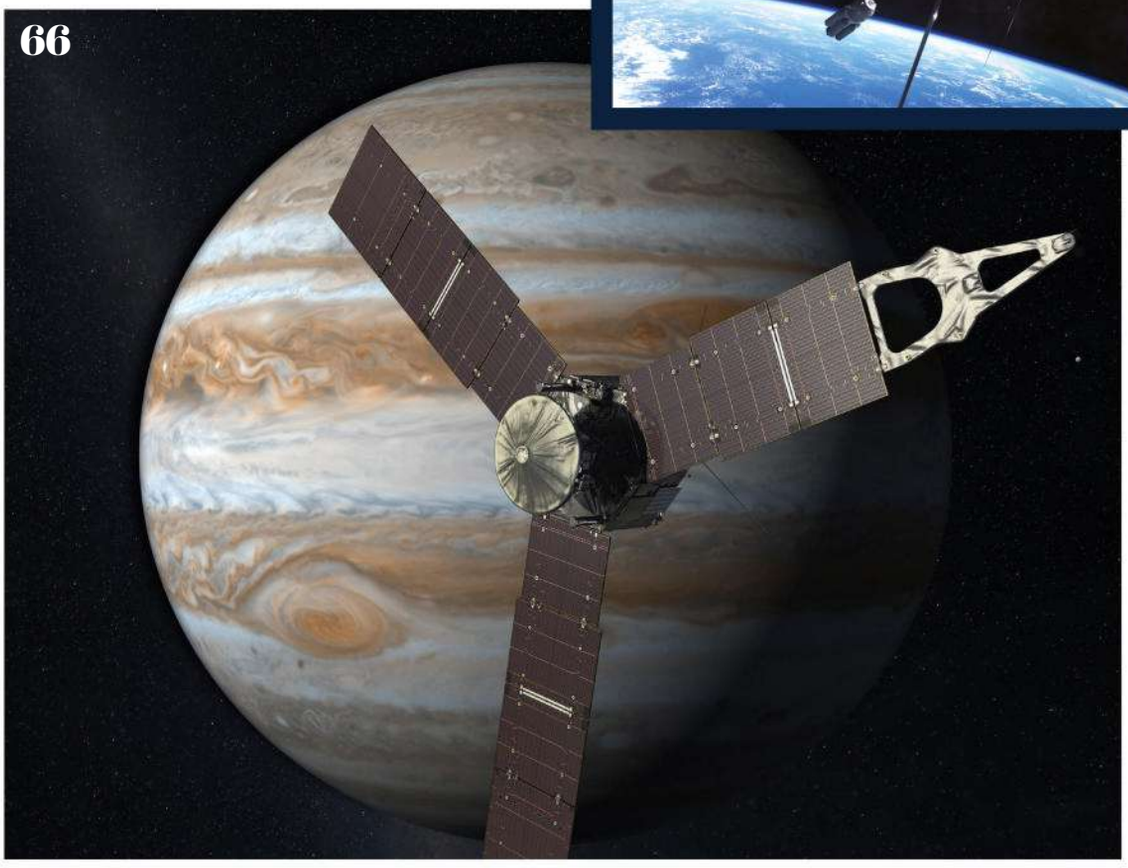


WIN!

CELESTRON STARSENSE EXPLORER DOBSONIAN 15

3 July 2023

The wreckage of a cosmic clash of the titans

A new image from the James Webb Space Telescope shows that when it comes to galaxies, appearances can be deceiving. The picture shows a serene-looking orange-red galaxy, but this cosmic spiral of gas, dust and stars hides a violent past, representing the wreckage of a massive collision between two earlier galaxies that occurred around 500 million years ago. The galaxy in question is NGC 3256, which lies around 120 million light years from Earth and is a member of the Hydra-Centaurus Supercluster. Hints at the chaotic past of this swirl-like galaxy are hidden within the Webb image in the form of long tendrils of shining dust and stars which extend outwards from the main body of the galaxy and the brightest portions of NGC 3256.

The study of these cosmic collisions can teach astronomers a great deal about how galaxies like our own, the Milky Way, grow by merging with other galaxies. As this galactic growth results in the merging and growth of black holes, studying wreckages like NGC 3256 could also help solve the mystery of how the supermassive black holes at the hearts of most galaxies can grow to masses equivalent to millions or even billions of times that of the Sun.

The historic merger that created NGC 3256 is also responsible for an intense burst of star formation in the galaxy. When galaxies collide, they channel gas and dust together into dense clouds to become the raw material needed for new stars to be born. The stunning image was created by Webb using data from its Near Infrared Camera (NIRCam) and its Mid-Infrared Instrument (MIRI).

© ESA/Webb, NASA

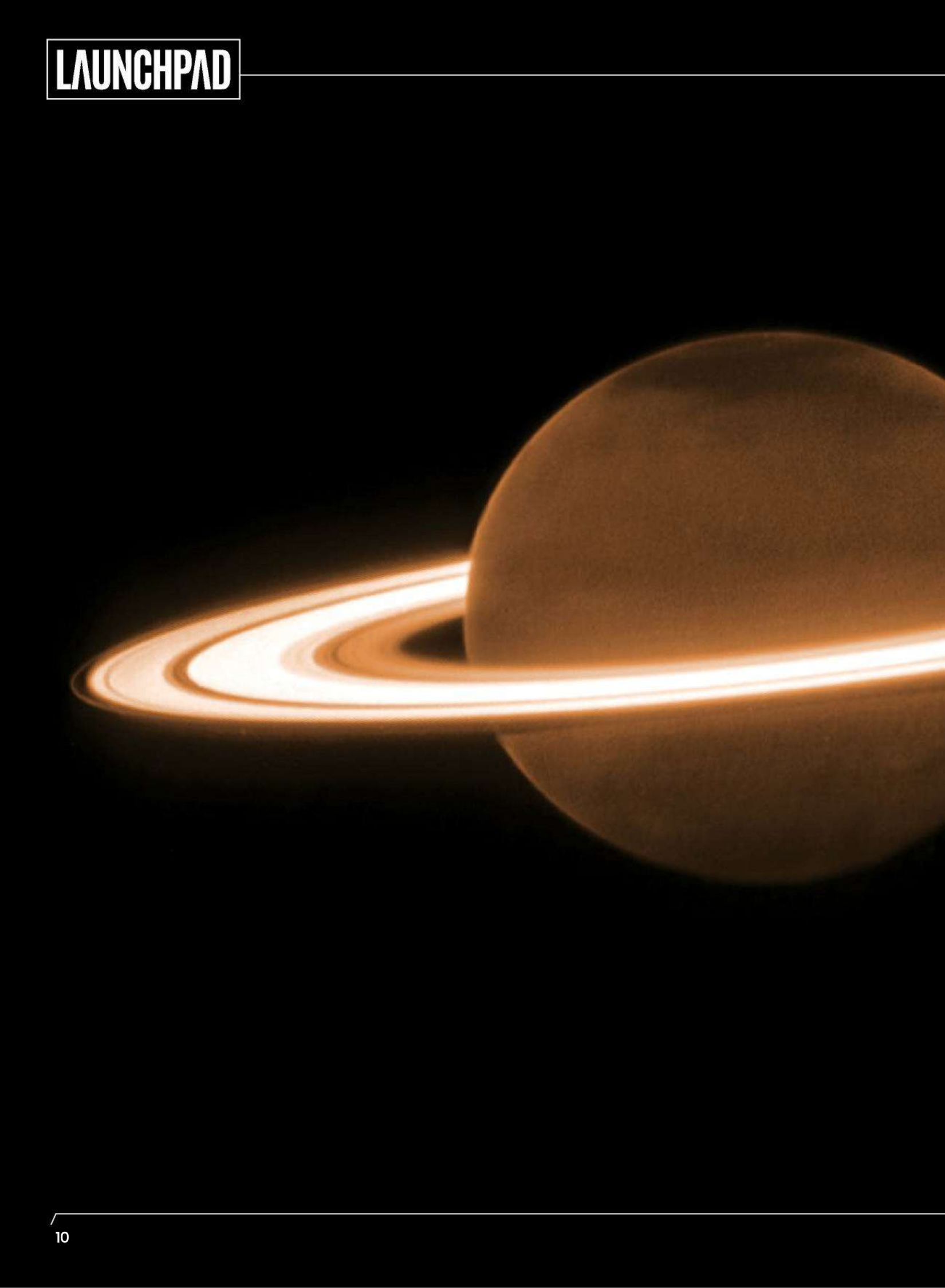
21 June 2023

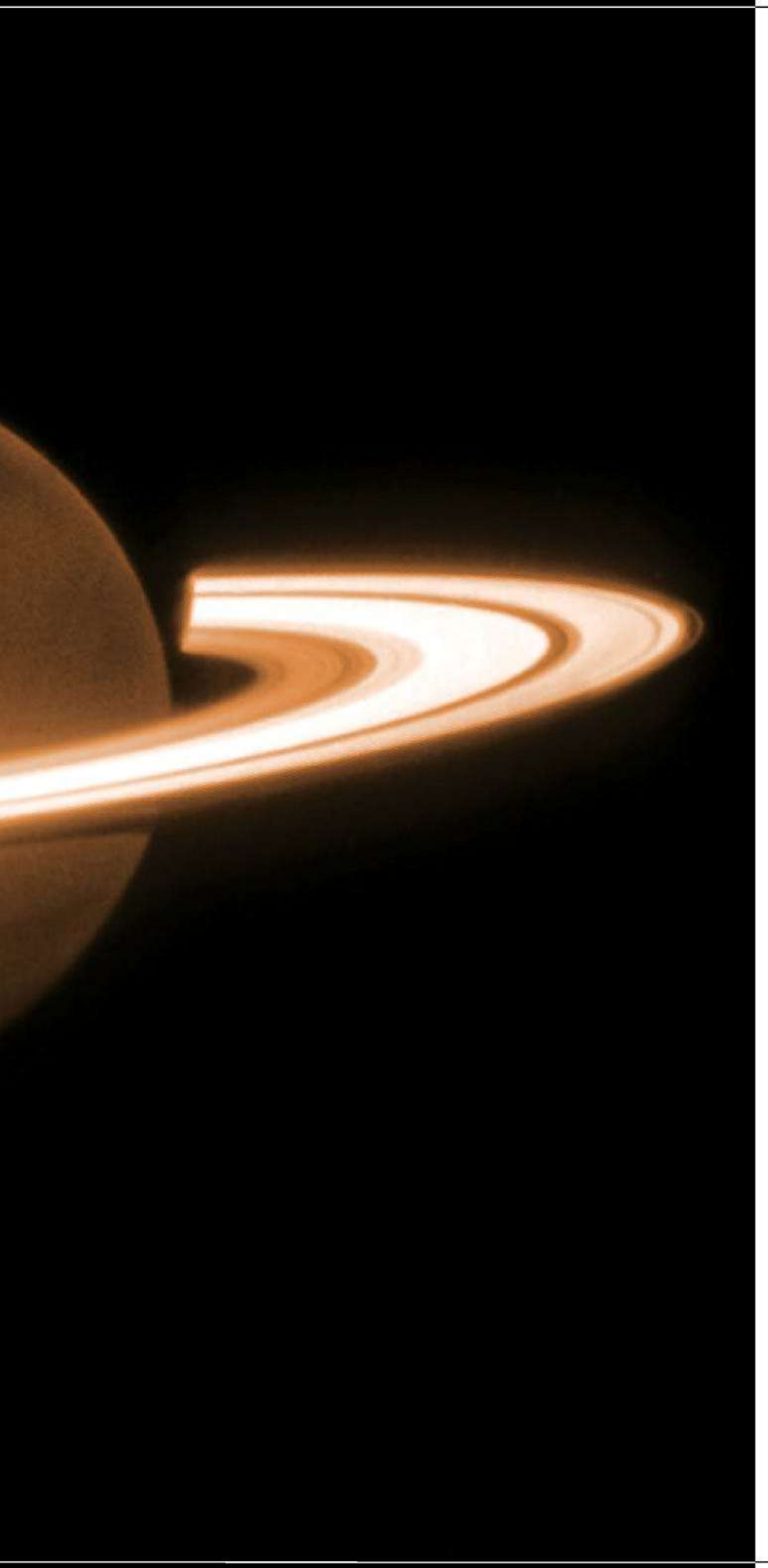
A dark nebula dominates this gorgeous new view of Orion

Dark, billowing clouds sweep across a stunning new view of a large star-forming area of the constellation of Orion. These dense interstellar clouds of gas and dust comprise a dark nebula formally known as LDN 1622. Dark nebulae are so named because their thick interstellar dust obscures light from nearby stars and other neighbouring objects. LDN 1622 is located 1,300 light years from Earth in the nearby Orion molecular cloud complex, a star-forming region teeming with young stars. It's located near the plane of our Milky Way galaxy, close to the belt and sword of the constellation.

The recent image was taken using the Nicholas U. Mayall Telescope at Kitt Peak National Observatory in Arizona, which is operated by NOIRLab. Astronomers captured this view of LDN 1622 using the telescope's wide-field camera, called Mosaic3 – the predecessor of the Mayall Telescope's Dark Energy Spectroscopic Instrument (DESI), which began operations in 2020 as the most powerful multi-object survey spectrograph in the world. "This swap highlights one of the benefits of ground-based astronomy: the ability to upgrade and replace instruments as new technologies become available," NOIRLab officials said.

© NOIRLab





25 June 2023

Webb's view of Saturn

The first official photo of Saturn from the James Webb Space Telescope does not disappoint. On 30 June, NASA released a stunning Webb image that shows the Ringed Planet in a whole new light. The photo, captured on 25 June by the observatory's Near-Infrared Camera, "is already fascinating researchers," NASA officials said. "Saturn itself appears extremely dark at this infrared wavelength observed by the telescope, as methane gas absorbs almost all of the sunlight falling on the atmosphere," they added. "However, the icy rings stay relatively bright, leading to the unusual appearance of Saturn in the Webb image."

The newly released image was captured during a 20-hour-long Saturn-observing campaign. While Saturn's rings are the clear star of the new photo, it also highlights Enceladus, Dione and Tethys, three of Saturn's 145 known moons. Enceladus is of particular interest to astrobiologists because the satellite is thought to possess an ocean of liquid water beneath its icy shell. The moon blasts some of its subsurface water out into space via geysers near its south pole, dramatic features discovered by NASA's Cassini probe back in 2005 and observed recently by Webb.

© NASA, ESA

Metal clouds turn a scorching-hot exoplanet into the universe's largest mirror

Reported by Robert Lea

Astronomers have discovered the most reflective planet outside the Solar System ever seen. The ultra-hot extrasolar planet, or exoplanet, acts like a cosmic mirror because it's covered by reflective clouds of metal. The planet, designated LTT 9779 b, is located around 264 light years from Earth and reflects around 80 per cent of the light that shines on it from its parent star. As a comparison, Earth reflects just 30 per cent of the light that falls on it from the Sun. The ultra-hot LTT 9779 b is so reflective that it's the first exoplanet found that gives the Solar System's shiniest planet, Venus, a run for its money – Venus has a thick layer of cloud that reflects around 75 per cent of incident sunlight. The newfound exoplanet is almost five times as wide as Earth, meaning it's also the largest cosmic mirror ever discovered. "Imagine a burning world close to its star, with heavy clouds of metals floating aloft, raining down titanium droplets," Diego Portales University astronomer James Jenkins said.

While LTT 9779 b was first discovered by NASA's Transiting Exoplanet Survey Satellite (TESS) in 2020, the world's highly reflective nature wasn't uncovered until a follow-up investigation by the European Space Agency's exoplanet-hunting spacecraft, CHaracterising ExOPlanet Satellite (CHEOPS). LTT 9779 b is around the size of the Solar System ice giant Neptune. Coupled with its roasting temperature, it's classed as an ultra-hot Neptune. Initially, the high reflectivity of LTT 9779 b – a quality known as 'albedo' – was a mystery to scientists. This is because most planets, other than ice worlds or planets with reflective cloud layers like Venus, have low albedos as a result of their atmospheres or surfaces absorbing starlight, thus preventing it from being reflected back into space.

LTT 9779 b was predicted to have a low albedo because, with a surface temperature of around 2,000 degrees Celsius (3,650 degrees Fahrenheit) on the side of the exoplanet that permanently faces its star, it should be too hot to form clouds of water. This high temperature should make LTT 9779 b too hot even for clouds of metals or glass to form. "It's a planet that shouldn't exist," says research co-author and Observatory of Côte d'Azur researcher Vivien Parmentier. "We expect planets like this to have their atmosphere blown away by their star, leaving behind bare rock."

The existence of such a planet prompted researchers to explore other theories for how these metal clouds formed. "It was really a puzzle until we realised we should think about this cloud formation in the same way as condensation forming in a bathroom after a hot shower," Parmentier added. "To steam up a bathroom, you can either cool the air until water vapour condenses or you can keep the hot water running until clouds form because the air is so saturated with vapour that it simply can't hold anymore."

The team thinks that LTT 9779 b got its metal clouds and high albedo when its atmosphere was oversaturated with silicate and metal vaporised by scorching hot temperatures on the planet's permanent dayside. The reflective nature isn't its only extraordinary quality, however. The exoplanet is also an example of a planetary type that has eluded astronomers for decades and remains mysterious.

An illustration of the exoplanet LTT 9779 b as it orbits its star

NASA's Perseverance rover works at a rocky outcrop called Skinner Ridge in Mars' Jezero crater

Perseverance rover digs up a diverse set of organic molecules on the Red Planet

Reported by Charles Q. Choi

Perseverance has found a diverse menagerie of organic molecules in a Martian crater. Organic compounds are molecules composed of carbon, and often include other elements such as hydrogen, oxygen, nitrogen, phosphorus and sulphur. Previously, scientists had detected several types of organic molecules of Martian origin – in meteorites blasted off Mars by cosmic impacts that landed on Earth, and in Gale crater on the Red Planet, which NASA's Curiosity rover has been exploring since 2012. "They're an exciting clue for astrobiologists, since they're often thought of as the building blocks of life," Sunanda Sharma, a planetary scientist at the California Institute of Technology, said. "Importantly, they can be created by processes not related to life." As such, investigating what organic molecules exist on the Red Planet and how they were created is key to understanding what may or may not be linked to life on Mars. "As planetary scientists and astrobiologists, we're very careful with laying out claims. Claiming that life is the source of organics or possible biosignatures is a last-resort hypothesis, meaning we'd need to rule out any non-biological source of origin."

In a new study, Sharma and her colleagues analysed data from the rover. In February 2021, Perseverance landed within Jezero, the site of an ancient lake basin that prior work suggested displayed high potential for past habitability. The crater floor also possesses clays and other minerals that may preserve organic materials. The scientists examined data from the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instrument onboard Perseverance. SHERLOC is the first tool on Mars capable of conducting fine-scale mapping and analysis of organic molecules.

The researchers focused on SHERLOC data from Máaz and Séítah, two rock formations on the Jezero crater floor. When ultraviolet light from SHERLOC illuminates organic compounds, they can glow, much like material beneath a blacklight. The fingerprint of wavelengths in the glow from a molecule can help identify it. Sharma and her colleagues found signs of organic molecules in all ten targets that Perseverance drilled into at Máaz and Séítah, covering a span of time from at least 2.3 billion to 2.6 billion years ago. These "point to the possibility that building blocks of life could have been present for a long time on the surface of Mars, in more than one place," Sharma said.

The scientists discovered evidence of many different classes of organic molecules. These occurred in a variety of patterns within Máaz and Séítah, suggesting they might have originated from a number of different minerals and mechanisms of formation. These organic compounds mostly appeared connected to minerals linked to water. "Seeing that the possible organic signals differ in terms of type, number of detections and distribution between the two units of the crater floor was surprising and exciting," Sharma said. "That opens the possibility of different formation, preservation or transportation mechanisms across the crater and, more broadly, the surface of Mars."

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NASA doubles its spacesuit options for Artemis astronauts, the Moon and ISS crews

Reported by John Loeffler

NASA has put out the call to double its options for new spacesuits on the International Space Station and for future Artemis astronauts to use while walking on the Moon. The space agency issued a new $10 million (£7.8 million) task order on 10 July for new suit options from Axiom Aerospace and Collins Aerospace, building upon already existing contracts with the companies to provide suit designs for extravehicular activities or spacewalks. NASA initially picked Axiom to build a Moon spacesuit for Artemis astronauts, while Collins has been working on a new suit for spacewalking astronauts working in weightlessness outside the International Space Station (ISS).

Axiom will now redesign its Moon suit so it can also be used for ISS operations, while Collins will work to assess and modify its suit design to make it capable of lunar surface operations. Each company will receive $5 million (£3.9 million) for the work.

"Our next-generation spacesuit design is nearly 90 per cent compatible with a lunar mission," Dave Romero, Collins Aerospace's director for EVA and human surface mobility systems, said. "This formal contract award will support continued efforts to modify our next-generation spacesuit, making it suitable for tasks on the Moon."

The new task orders should also help spur new suit innovations through competition between the two companies, while also providing a backup plan for NASA in case one of the suit designs runs into issues."These task orders position NASA for success should additional capabilities become necessary or advantageous to NASA's missions as the agency paves the way for deep-space exploration and commercialisation of low-Earth orbit," Lara Kearney, manager of the Extravehicular Activity and Human Surface Mobility program at NASA's Johnson Space Center in Houston, said. "Using this competitive approach, we will enhance redundancy, expand future capabilities and further invest in the space economy."

The two companies will now begin modifying their respective suit designs to adapt them to operate in the two vastly different environments of low-Earth orbit and the lunar surface. Once these initial redesigns are put down on paper, NASA will review and assess the two designs and determine whether one or both will be given the go ahead for further development.

Buried oceans may be common on icy exoplanets

Reported by Robert Lea

A new analysis of exoplanets suggests there's a much greater chance of these worlds hosting liquid water, an essential ingredient for life on Earth. The universe could be filled with more habitable planets than scientists believed, with a greater chance of these worlds possessing environments in which alien life could develop, even if they have icy outer shells. "We know that the presence of liquid water is essential for life. Our work shows that this water can be found in places we had not considered," Rutgers University scientist Lujendra Ojha said. "This significantly increases the chances of finding environments where life could develop."

Ojha and colleagues found that even exoplanets with frozen surfaces could have subsurface oceans of liquid water. "Before we started to consider this subsurface water, it was estimated that around one rocky planet in every 100 stars would have liquid water," Ojha explained. "The new model shows that, if the conditions are right, this could approach one planet per star. So we are 100 times more likely to find liquid water than we thought."

Because there are about 100 billion stars in the Milky Way, "that represents really good odds for the origin of life elsewhere in the universe," he added. The researchers investigated planets found around the most common type of star in our galaxy, red dwarfs, which are smaller and cooler than the Sun. Not only do red dwarfs, also known as M dwarfs, make up about 70 per cent of the stars in the Milky Way, but they are also the stars around which the majority of Earth-like rocky worlds have been found.

The team considered two ways in which rocky planets with an icy shell could be heated from below, allowing them to maintain underground liquid water. "We modelled the feasibility of generating and sustaining liquid water on exoplanets orbiting M dwarfs by only considering the heat generated by the planet," Ojha said. "We found that when you consider the possibility of liquid water generated by radioactivity, it's likely that a high percentage of these exoplanets can have sufficient heat to sustain liquid water." Another possible mechanism that could help maintain liquid water below a frozen planetary shell suggested by the team arises as a result of the gravitational influence of a larger body, causing the interior of an outwardly frozen world to endlessly churn.

NASA has asked two spacesuit providers to make more versions of their spacesuits for use on the Moon and in open space

Many exoplanets may have oceans beneath their icy shells, like the Jupiter moon Europa, seen here by NASA's Galileo

© NASA/JPL-Caltech

WIN

CELESTRON STARSENSE EXPLORER DOBSONIAN

Courtesy of Celestron, you can kick-start your stargazing hobby with this month's competition

Celestron has reinvented the Dobsonian telescope with the StarSense Explorer – the first Dobsonian that uses your smartphone to analyse the night sky and calculate its position in real-time. This large-aperture Celestron StarSense Explorer is ideal for serious beginners thanks to the app's user-friendly interface and detailed tutorials. It's like having your own personal tour guide of the night sky. The large aperture will ensure that you won't outgrow the telescope as you continue on in your astronomical adventures.

With a large eight-inch Newtonian reflector optical tube, this telescope has enough light-gathering ability to bring out impressive detail in celestial objects while remaining remarkably portable. You can expect sharp, bright views of Jupiter's four Galilean moons, its cloud bands and Great Red Spot; the rings of Saturn; the gaseous glow of the Orion Nebula; dust lanes in the Lagoon Nebula and our neighbour galaxy, Andromeda. Compared to the StarSense Explorer DX 130AZ, the eight-inch Dobsonian has 240-plus per cent more light-gathering area, providing better views of faint objects.

This telescope also comes with a high-quality Crayford focuser. The Crayford design provides precise and smooth movements without focus shifting. It also includes a two to 1.25-inch adapter and a two-inch extension tube, so you can use virtually any 1.25 or two-inch telescope eyepiece with your StarSense Explorer Dobsonian. The focuser also features a thumbscrew so you can lock in the sharpest focus.

To be in with a chance of winning, answer this question:

Which planet has the most mass?

A: Saturn

B: Neptune

C: Jupiter

Competition ends on 7 September 2023

Enter via email at **space@spaceanswers.com**

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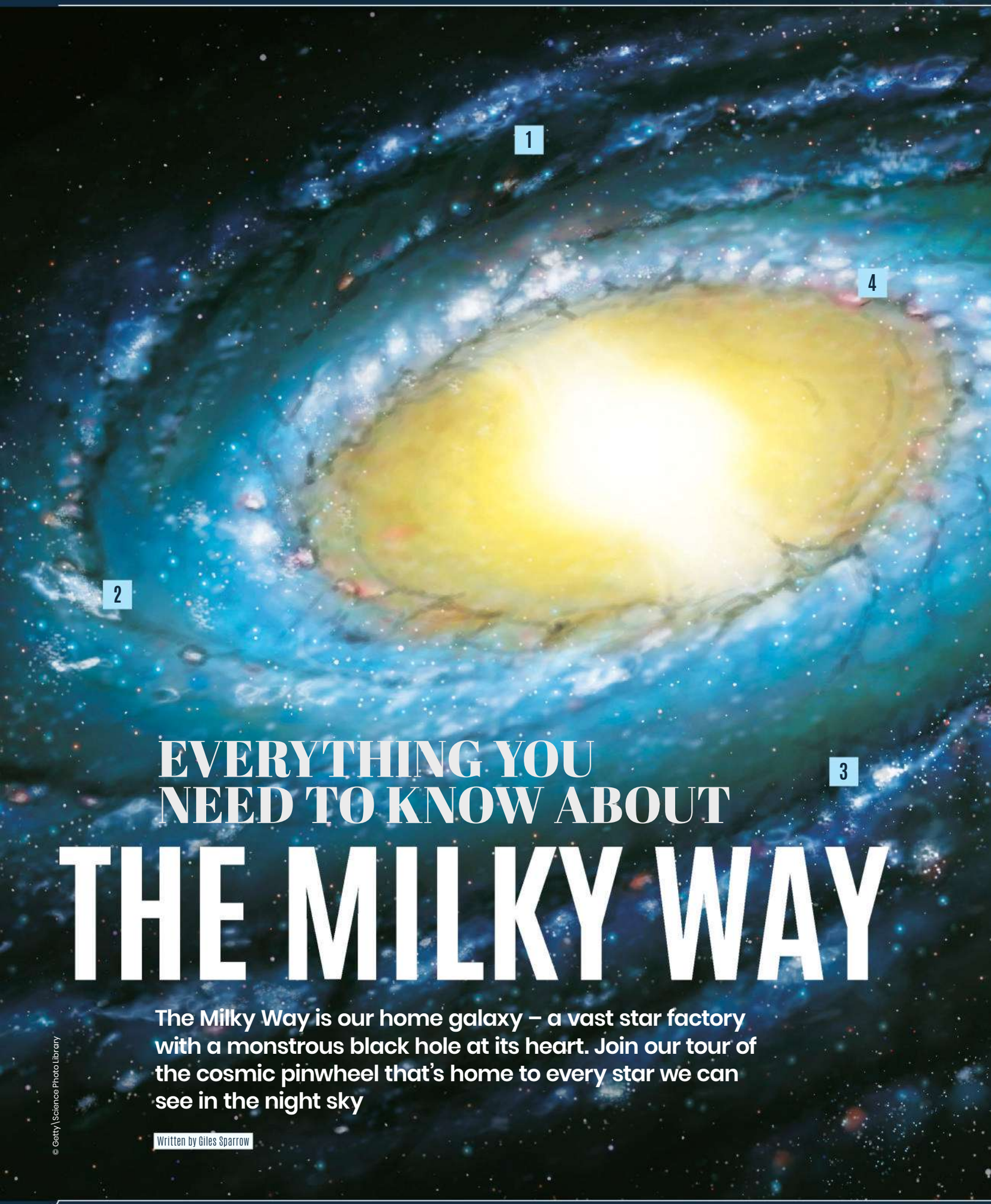


EVERYTHING YOU NEED TO KNOW ABOUT THE MILKY WAY

The Milky Way is our home galaxy – a vast star factory with a monstrous black hole at its heart. Join our tour of the cosmic pinwheel that's home to every star we can see in the night sky

Written by Giles Sparrow

© Getty | Science Photo Library

SPIRAL IN SPACE

The shape of the Milky Way in the sky reveals that our Solar System is embedded in a broad but thin plane of stars. Looking away from the band of the Milky Way, we see past the relatively nearby stars that lie in our part of this plane into apparently empty intergalactic space. However, when we look across the plane we see many more stars extending to greater distances; their combined light forms the band of the Milky Way. Radio astronomy observations, which can see past dense clouds of stars and dust to map the distribution of hydrogen gas clouds across the plane, confirm that our galaxy has a spiral structure broadly similar to many other galaxies in the sky – in fact, it's a type of galaxy known as a barred spiral.

The latest measurements suggest the Milky Way is a flattened disc roughly 100,000 light years in diameter and about 1,000 light years deep – although stray trails of stars extend much further out. Stars, gas and dust in the disc slowly orbit around a central bulge of stars roughly 20,000 light years across in the direction of Sagittarius. The spiral arms are concentrations of particularly bright stars and star-forming nebulae that run across the disc, beginning at either end of an elongated stellar bar that extends from the bulge. In total, the Milky Way is thought to contain between 100 billion and 400 billion stars, with our own Solar System located about 26,000 light years from the centre, roughly midway between the two major spiral arms in a region called the Local Arm or Orion Spur.

"The Milky Way is a flattened disc roughly 100,000 light years in diameter and about 1,000 light years deep"

5

1 Norma Arm

Extending out from the centre of the Milky Way, the Norma Arm is a somewhat minor spiral arm with a radius of up to 50,555 light years across. It's split into two with the second part of it, the Outer Arm, stretching out the furthest.

2 Scutum-Centaurus Arm

A curving streamer of diffuse stars, gas and dust makes up this arm. Beginning near the galaxy's core as the Scutum Arm, it blends into the Centaurus Arm, hitting an extremely intense region rich in the birth of young stars.

3 Orion-Cygnus Arm

This minor spiral arm, which measures around 3,500 light years across and some 10,000 light years in length, is where our home can be found, nestled in the Orion Arm about 26,000 light years from our galaxy's centre.

Our Solar System

4 Carina-Sagittarius Arm

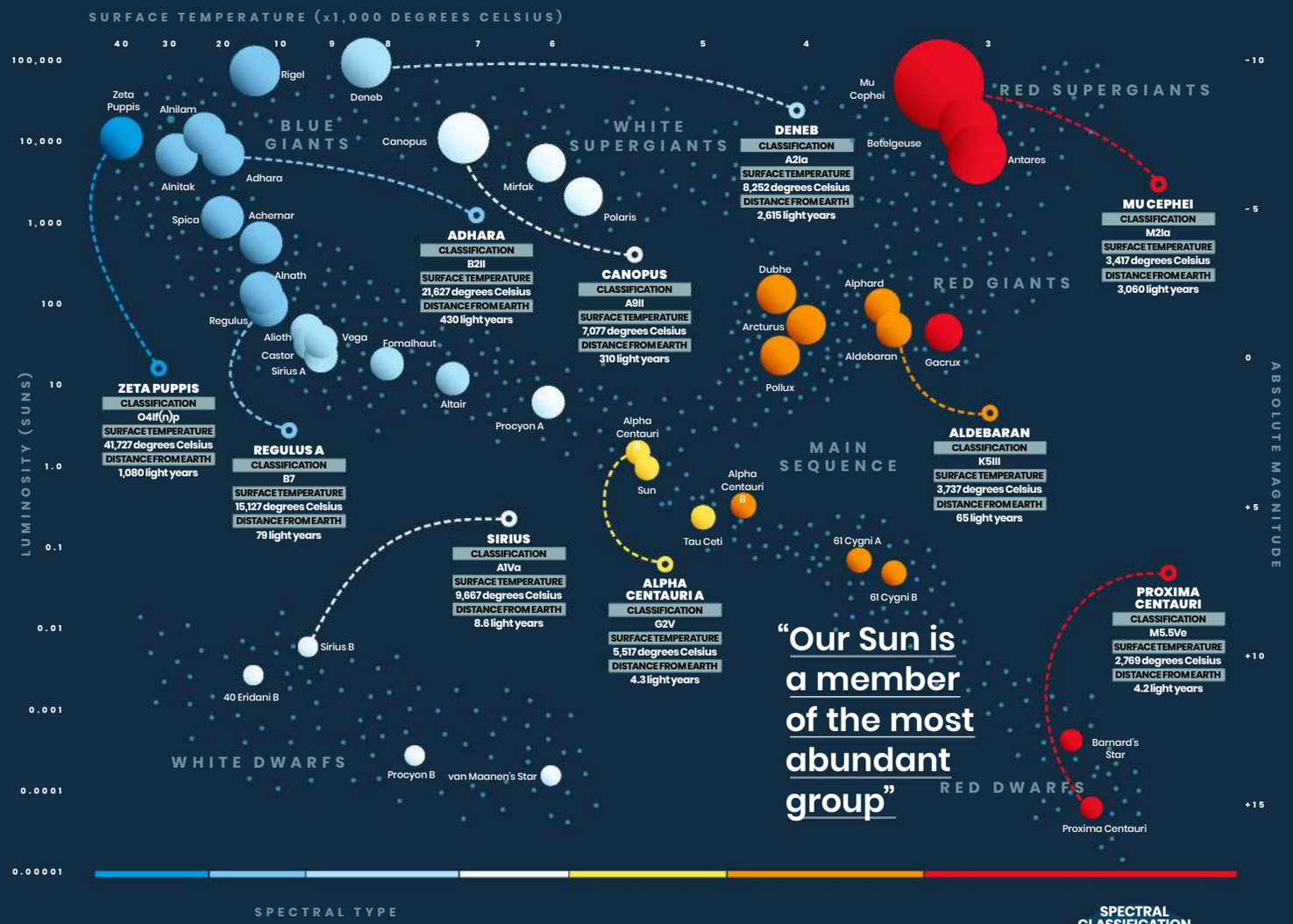
Home to a large number of large, low-density H II regions and gigantic molecular clouds, infrared observations taken by the Spitzer Space Telescope uncovered an incredible amount of young stars being born in the Carina-Sagittarius Arm.

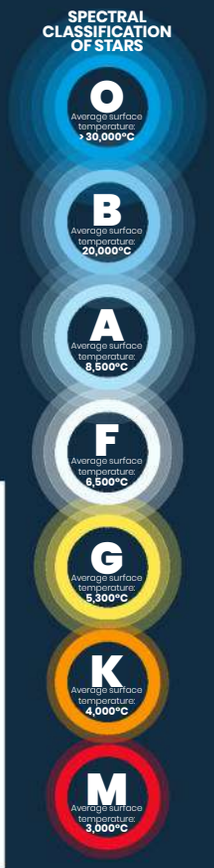
5 Perseus Arm

One of the major spiral arms, the Perseus Arm can be seen in the direction of the constellation of Perseus from Earth, where you'll find Messier objects such as the Crab Nebula (Messier 1), as well as open clusters Messier 38 and Messier 52, marking its path.

Outer arm

Spiral arms of the Milky Way are visible from Earth under dark conditions





BAND AROUND THE SKY

From our point of view on Earth, the Milky Way forms a belt of pale light that wraps around the sky, passing through familiar constellations such as Cassiopeia and Cygnus in the northern sky and the Southern Cross and Carina in the far south. Ancient Greek stargazers imagined it as a stream of milk spilt by Hera, queen of the gods, and named it 'galaxias kyklos', the Milky Circle. Later, Roman astronomers translated this to via lactea, the Milky Way.

The Milky Way's band forms a backdrop to many of the brightest stars in the sky, and binoculars or a telescope reveal that its light comes from countless stars too faint and close together to distinguish with the naked eye. It is also studded with so-called 'deep-sky' objects associated with different stages of the stellar life cycle, such as the emission nebulae associated with starbirth, bright open clusters of young stars and shell-like planetary nebulae produced by the death of stars like the Sun. The band is at its broadest and brightest in the direction of Sagittarius and at its faintest and thinnest around Cassiopeia. In several places – most notably within Cygnus – clouds of opaque dust block the more distant star clouds to give the impression of gaps in the Milky Way.

© NASA; Alamy

THE MILKY WAY BY NUMBERS

100 TO 400 BILLION
The estimated number of stars in the Milky Way

210 KILOMETRES PER SECOND
The typical speed of a star in the galactic disc in its orbit

190 MILLION YEARS
The approximate rotation period of the Milky Way's spiral structure

4.1 MILLION SUNS
The mass of the Milky Way's central supermassive black hole, Sagittarius A*

1.5 TRILLION SUNS
The latest estimate of the Milky Way's total mass

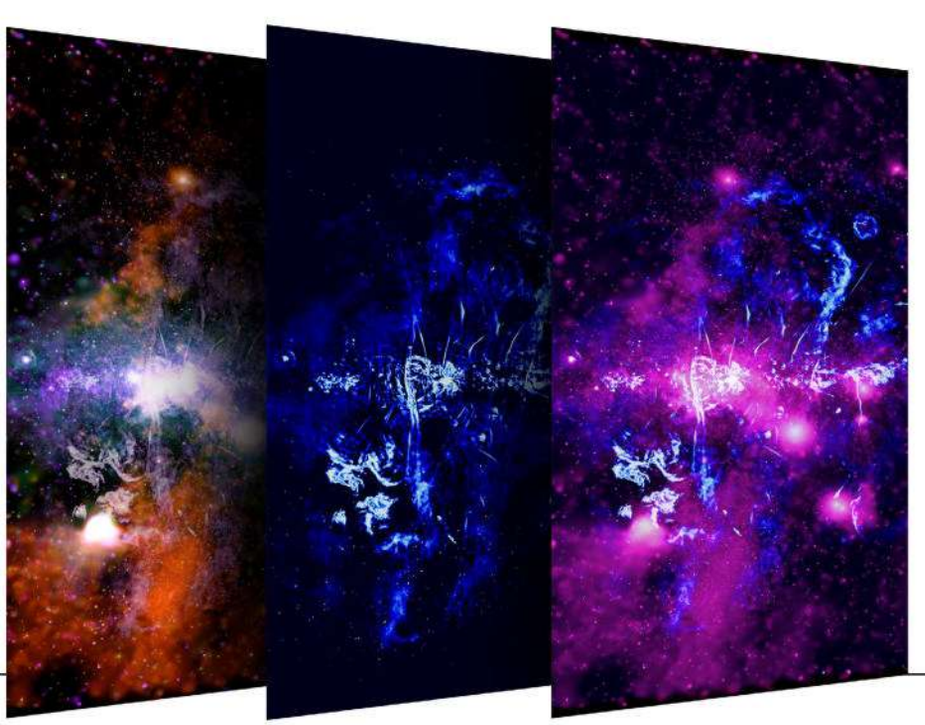
2.5 MILLION DEGREES
Temperature of the thin gas that fills the galactic halo region in Celsius

UNFOLDING STRUCTURE

Astronomers are still making new discoveries about the shape of the Milky Way. For instance, maps of gas flow near the centre of the galaxy first suggested the influence of a large bar of stars running across the bulge in the 1960s, but this bar was only confirmed using infrared observations in 2005. The bar is thought to create an alignment among the orbits of objects further out, producing the 'density wave' effect that generates the spiral arms.

Improved maps of both hydrogen clouds and star distribution have also shown that the Milky Way's disc has two components – a central thin disc less than 1,000 light years deep and an outer thick disc around 8,000 light years deep. The sparse stars of the thick disc have fewer heavy elements than those of the thin disc, suggesting that they formed at an earlier stage in the Milky Way's history. What's more, the entire disc is significantly warped – if we could see it from outside, the Milky Way would have an S-shaped profile.

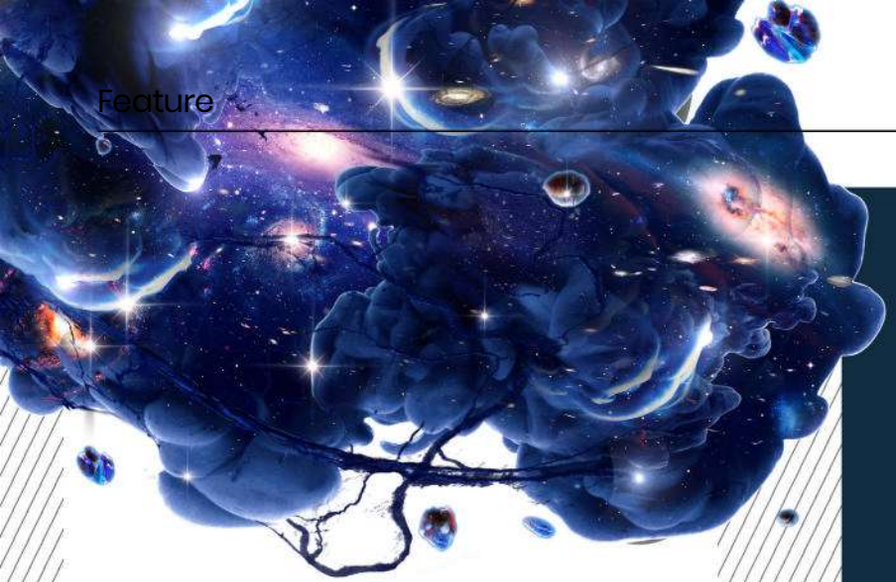
Even the exact number and nature of the spiral arms is still open to debate. When the spiral is mapped in terms of gas and young stars there seem to be four major arms, known as the Perseus Arm, Scutum-Centaurus Arm, Carina-Sagittarius Arm and the Norma Arm, which is linked to the Outer Arm that wraps around the outside of the entire disc. However, surveys of aged red giant stars, which can be seen over greater distances in near-infrared light, suggest there are just two 'major' arms: Perseus and Scutum-Centaurus.



STELLAR TRAFFIC JAMS

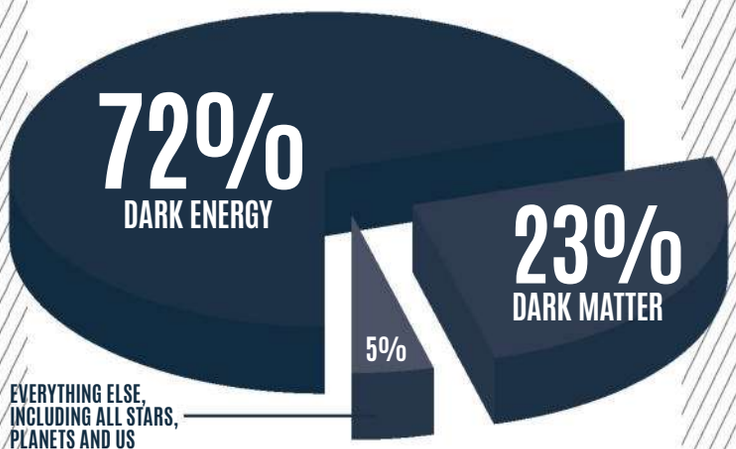
Although it's tempting to imagine spiral arms as physical chains of stars circling the galactic core, this cannot actually be the case due to an effect known as differential rotation – the fact that stars and other material close to the centre orbit much more rapidly than those further out. Any such chains of stars would have long since wound themselves tightly into the bulge and disappeared.

Instead the arms actually resemble slow-moving stellar traffic jams – spiral 'density waves' created in regions where orbiting objects tend to slow down and crowd together near the outer reaches of their slightly elliptical orbits. Clouds of interstellar gas and dust entering these regions are compressed, triggering new star formation and creating glowing nebulae, while the newborn stars themselves form bright open clusters that define the spiral structure. Because the brightest and most massive stars live for just a few million years, they die in supernova explosions before their orbits can carry them far from their birthplace, ensuring that the bright spiral structure remains sharply defined and regenerates itself continuously. Only fainter stars like the Sun survive for long enough to orbit in the more general galactic disc.



DARK MATTER MYSTERY

Stars close to the centre of the galaxy orbit faster than those further out – the Sun orbits the centre in roughly 212 million years. But when astronomers measure stars near the outer edge of the galaxy, they find the motion does not slow down as much as they would predict if the distribution of the galaxy's mass matches that of its stars and other visible material. The faster motion of outlying stars suggests that there are vast quantities of mass further out – both beyond the visible edge of the galactic disc and in the apparently empty halo region above and below. The rotation patterns of our galaxy and others are a key piece of evidence for so-called 'dark matter', which is thought to account for five-sixths of the mass of the entire universe and about 90 per cent of the Milky Way's mass. Our galaxy has provided an ideal laboratory for astronomers to test theories about the nature of dark matter, allowing them to dismiss the idea that it's simply made of conventional but hard-to-detect objects such as rogue planets, burnt-out dwarf stars or black holes in the galactic halo. Instead it seems to be a truly exotic form of matter that is not only dark, but entirely transparent and immune to interactions with any form of electromagnetic radiation, giving itself away only through its gravitational influence. Some researchers believe that the Milky Way's dark matter halo could extend in a disc up to 2 million kilometres (1.2 million miles) across, embedded with lonely scattered stars almost halfway to our nearest large neighbouring galaxy.



GALACTIC HISTORY

The oldest known stars of Population II have been shining for about 13 billion years, so by some measures the Milky Way isn't much younger than the universe itself. However, the oldest disc stars are much younger – around 9 billion years old. Based on the process of galaxy formation, we can see in the distant early universe that it's likely the Milky Way began life in the merger of several smaller irregular galaxies. Rippling shock waves compressed their gas to trigger enormous waves of star formation and create super-sized star clusters, which eventually became today's globular clusters. But the shock waves also heated the gas clouds until they were too hot and fast-moving to coalesce under gravity, expanding instead to form a hot halo around the chaotic central ball of stars. As shorter lived stars with higher masses aged and died off, only the lower mass Population II stars were left.

From about 10 billion years ago, the cooling halo gases were able to coalesce once more around the core of the galaxy. Collisions herded them into a flattened disc, and the process of star formation re-ignited to create Population II stars. Each successive generation of these stars processes more of the galaxy's lightweight raw materials to form heavier elements, and their deaths – particularly the supernova explosions that mark the end of the most massive stars – enrich the interstellar medium with these elements, which are then incorporated into the next wave of stars. Our own Sun formed around 4.6 billion years ago.

"These elements are incorporated into the next wave of stars"

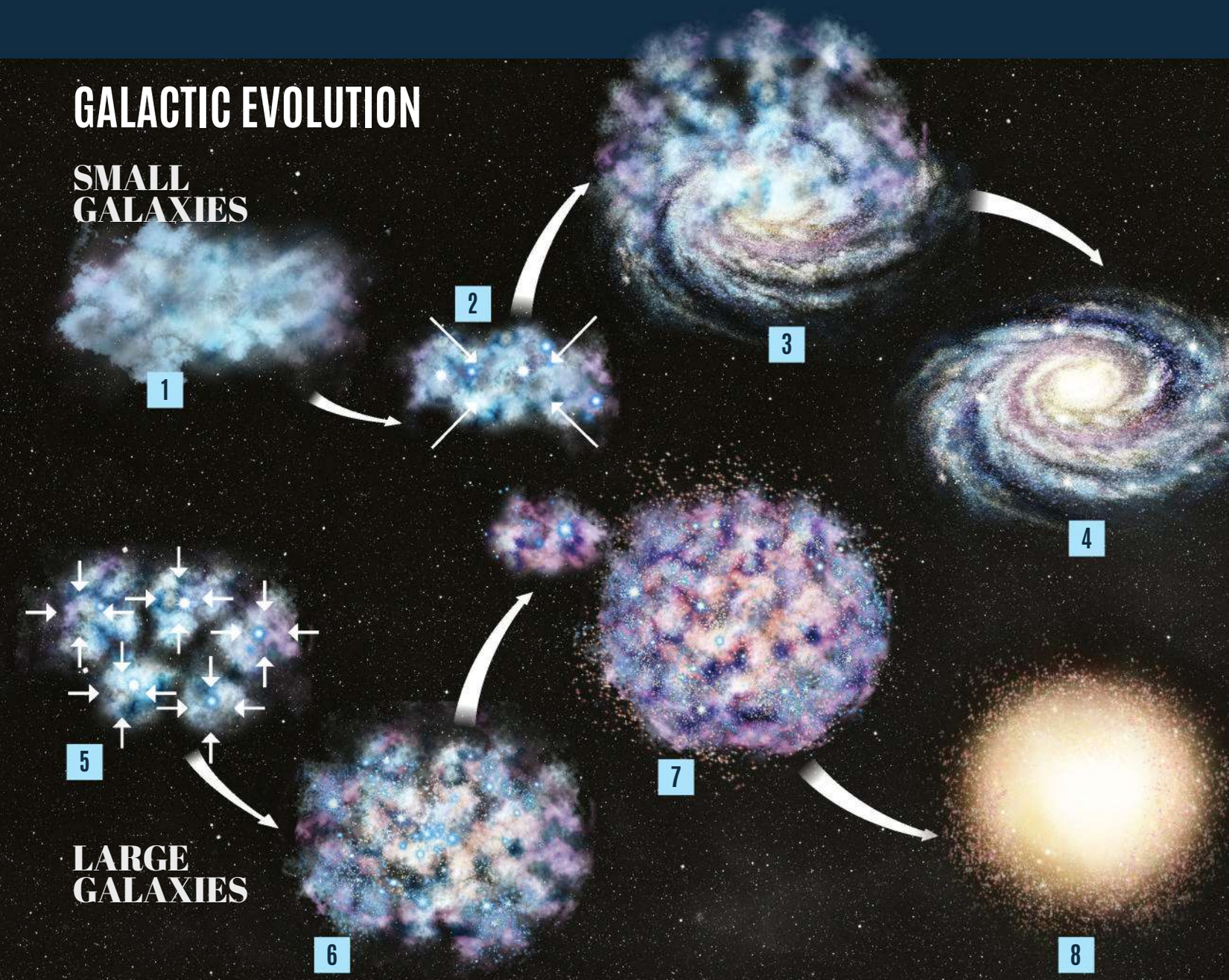
1 A lonely cloud of gas

In order for what astronomers call a 'small galaxy' to be made, a relatively large and isolated gas cloud is needed.

2 The making of stars

Under gravity the cloud will collapse because there's not enough pressure from the gas itself to fight against the force pressing it down. Baby stars are made in the fight between gravity and pressure.

GALACTIC EVOLUTION



3 Forming a disc
The matter spins quickly, causing a flattened disc-like structure. At the centre is a bulge where the older first-generation stars can be found. The rest of the disc is teeming with younger stars.

4 A galaxy with arms
Internal processes make the arms and bars found in spiral galaxies. However, if conditions are more favourable, a lenticular galaxy – an intermediate between an elliptical and a spiral – is made instead.

5 A team of gas clouds
Small clouds of gas collapsed early on to form the galaxy's very first stars.

6 A party of stars
These gas clouds, with their newly formed stars, clump together to make a larger cloud with a party of stellar populations.

7 Gaseous add-ons
There isn't much spinning going on during the making of a large galaxy. Instead the merging of nearby gas clouds stops any chance of a disc-like structure from forming.

8 A gigantic galaxy
Since most of the gas needed to make a new generation of baby stars was mopped up, no more can be made. What's left is a gigantic elliptical that's dominated by old stars.

© Tobias Roetsch

THE GALACTIC NEIGHBOURHOOD

The Milky Way and its immediate satellites form part of a small galaxy cluster called the Local Group, occupying a volume of space about 10 million light years across. The group contains several dozen galaxies in total, but these are mostly small 'dwarf spheroidal' star clouds. Aside from the Milky Way, the other major member is the Andromeda Galaxy – another spiral system that lies about 2.5 million light years away in the constellation of the same name.

At roughly 150,000 light years across, Andromeda is even larger than the Milky Way, but astronomers still aren't certain which galaxy is the more massive of the two. Andromeda and the Milky Way are currently approaching each other at a speed of about 110 kilometres (68 miles) per second, and are expected to collide in about 4 to 5 billion years, triggering waves of violent star formation and perhaps eventually coalescing into a giant elliptical ball of stars.

Andromeda has two bright satellite galaxies, catalogued as Messier 32 and Messier 110, but unlike the Milky Way's Magellanic Clouds, these are compact, elongated balls of stars known as ellipticals. A third spiral, the Triangulum Galaxy, lies about 3.2 million light years away in roughly the same direction as Andromeda.

Andromeda is the nearest spiral galaxy to Earth and is a popular target for astronomers

STELLAR POPULATIONS

Stars in the Milky Way come in two main types, known as populations. The stars of Population I are found in the spiral arms and the galactic disc between them. They are generally brighter and hotter and contain greater amounts of heavy elements. Like all stars, Population I are dominated by the lightweight gases hydrogen and helium, but these heavy elements boost the rate of nuclear fusion in their cores – this is why Population I stars tend to shine hotter and brighter than Population II stars of a similar mass, but it also means they have shorter life spans.

Population II stars are mostly crowded together in the central bulge, but they also form globular clusters – huge balls of hundreds of thousands of stars that follow their own orbits around the galactic centre and are often found in the apparently empty halo region above and below the disc. Population II stars tend to be smaller and fainter than the Sun, with cool red, orange or yellow surfaces. A combination of lower mass and a lack of heavy elements causes them to burn fuel at a reduced rate, giving them extremely long life spans – they are the oldest stars in our galaxy.

What are stars made of?

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Artificial

Large stars
Massive stars continue the nuclear fusion process longer than Sun-like ones, producing elements up to and including iron.

Big Bang
The two lightest elements in the universe, hydrogen and helium, were created in vast quantities by the Big Bang some 13.8 billion years ago.

Small stars
The later stages in the lives of stars like our Sun make a significant contribution to the overall amount of carbon, nitrogen, oxygen, neon and sulphur.

Supernovae
The heaviest natural elements in the universe are created during the uncontrolled burst of nuclear fusion that marks a supernova explosion.

Cosmic rays
Lithium, beryllium and boron owe their origins to the break-up of carbon and oxygen atoms in space when they are struck by high-energy particles from stars.

GALACTIC CANNIBAL

Our galaxy holds a number of smaller galaxies in orbit around it. Many of these are little more than sparse clouds of stars, but the biggest and brightest are substantial irregular galaxies with abundant star formation. The Large Magellanic Cloud (LMC) even shows hints of a bar and spiral structure. The LMC and Small Magellanic Cloud lie about 160,000 and 210,000 light years from Earth and are currently in an unusually close approach to the Milky Way, resulting in distortion to their shapes and leaving a trail of gas known as the Magellanic Stream along their path.

Some small galaxies that stray even closer to the Milky Way may eventually be torn apart by the encounter. The Sagittarius Dwarf Spheroidal Galaxy is an elongated cloud of stars on the opposite side of the galactic centre to Earth in an orbit that takes it above and below the poles of the Milky Way and occasionally passes through the disc. With each close encounter, stars are being torn away to form a sparse stellar stream along its orbit. Astronomers predict that the galaxy will disintegrate completely within a billion years.

The LMC is about one-hundredth the size of the Milky Way

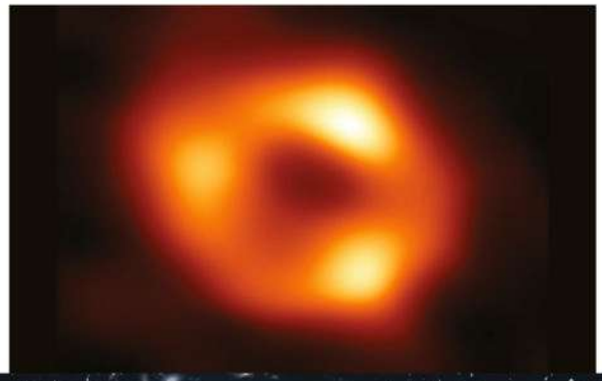
LIFE IN OUR GALAXY

Astronomers estimate that the Milky Way is home to at least as many planets as stars – 100 billion at a minimum. However, not all parts of the galaxy are suited to producing planets, let alone ones with the right conditions for life. Significant quantities of elements heavier than hydrogen and helium are needed in order for rocky terrestrial planets to arise as a byproduct of star formation, and so planets are naturally more likely to occur among the Population I stars of the galactic disc. However, some research suggests that an excess of these heavy elements will produce planetary systems with large numbers of gas giant planets, whose gravitational interactions may tend to disrupt the orbits of smaller worlds.

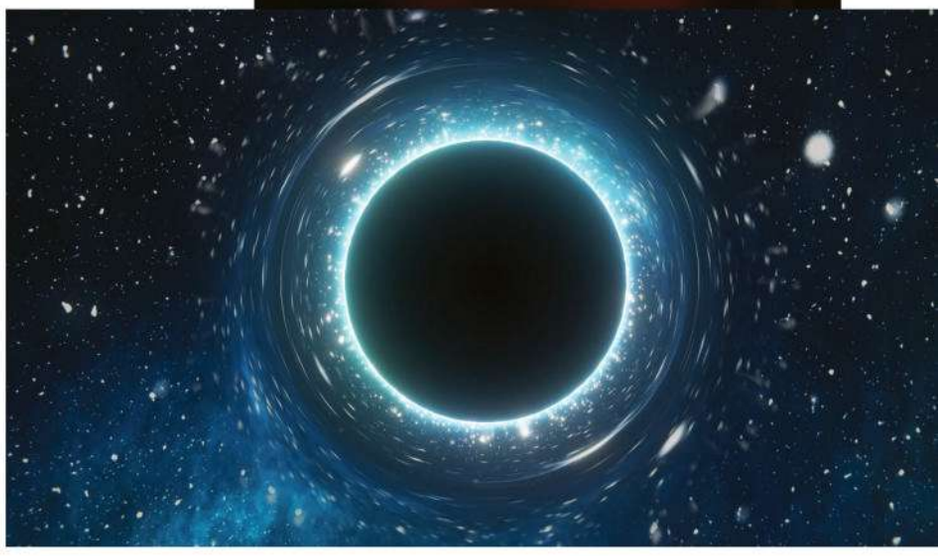
SURPRISE AT THE CENTRE

The very centre of our galaxy is home to a slumbering monster: a supermassive black hole. Objects like this are thought to lie at the hearts of most galaxies – they originated from the collapse of giant stars in the early days of the universe, then grew prodigiously by feeding on gas, dust and stars as galaxies coalesced, and by merging together as smaller galaxies collided to form larger ones. Today, most material stays well out of reach of the black hole, but radiation from a gentle stream of infalling gas turns it into a source of radio waves known as Sagittarius A*. Astronomers have confirmed the black hole's mass by mapping the orbits of stars near the galactic centre, revealing that they orbit an invisible object with the mass of about 4.1 million Suns and a diameter substantially smaller than the orbit of Mercury.

While the wider galactic bulge is dominated by sedate Population II stars, things are very different around Sagittarius A*, where it seems that the density of infalling gas allowed for a huge burst of star formation just a few million years ago. As a result, the galactic centre is home to some of the densest star clusters and most massive stars in our galaxy. Above and below the centre, meanwhile, lie two huge lobes of X-ray-emitting gas that extend for 25,000 light years into the halo. Astronomers believe that these are linked to the last time Sagittarius A* awoke and swallowed a substantial meal.



Sagittarius A* was imaged by the Event Horizon Telescope in 2017



Black holes are some of the strangest objects in the universe

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FUTURE TECH

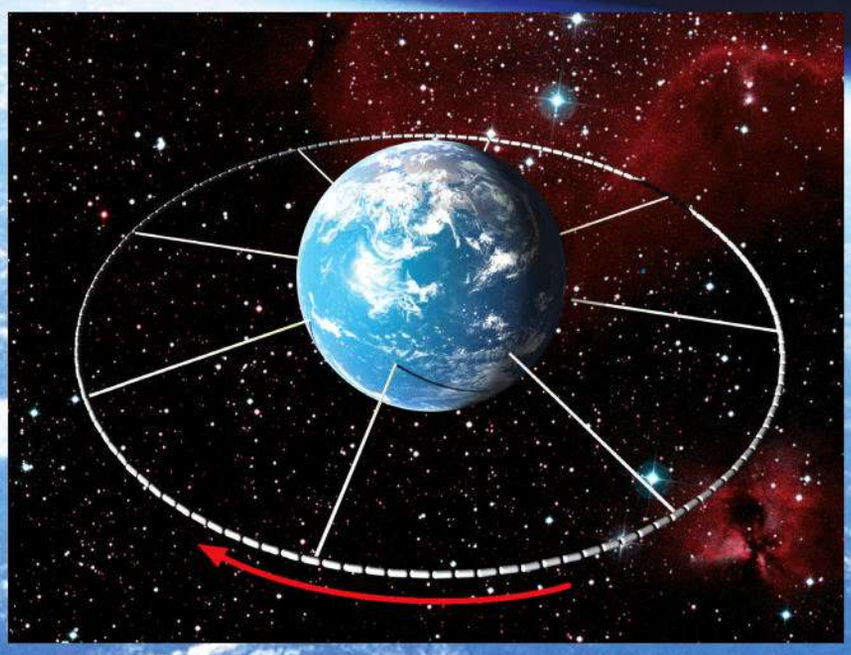
ORBITAL RINGS

These megastructures could ring around Earth to provide global transport systems

Today, transporting people and cargo into space is an extremely expensive, dangerous and time-consuming enterprise. It relies on rockets that can only take relatively small loads into Earth orbit. To make space more accessible, scientists have put forward the idea of building space elevators. These would consist of cables made of carbon nanotubes that would carry an elevator from the Earth's equator to a geostationary space station linked to a counter-mass. Linked to the space elevator is the concept of creating an orbital ring or orbital ring systems. As early as the 1870s, inventor Nikola Tesla thought that a solid structure built around the equator would "float freely and could be arrested in its spinning motion by reactionary forces". Using this orbital ring, he predicted that passengers could travel at a speed of around 1,600 kilometres per hour (990 miles per hour) around the globe.

A simple orbital ring could be made from cables or inflatable modules that could be constructed in space or transported in a space elevator. As this orbits the equator, ring stations ride on superconducting magnets to keep them positioned over the same point on Earth. By this means, space elevators can be attached to the ring stations. A better method of keeping the ring stations in a geostationary orbit is to attach them to the ring and accelerate the ring eastwards to counteract the motion of the rotating Earth. The benefit of this is that you can obtain a geostationary orbit without having to travel almost 36,000 kilometres (22,000 miles), as satellites have to do today to remain over the same area of Earth.

Another benefit of an orbital ring is that it could be moved to rotate over the Earth beyond the equator and even ring the Earth from pole to pole. By having several rings and connections between them, an extensive transport system could be built that would provide a global means of travelling to and from space. Such a megastructure would cost billions, but it would eventually make the cost of taking payloads into orbit extremely cheap, safe and efficient. Furthermore, similar rings could be built around the Moon and other planets to fully explore and exploit the resources of our Solar System.



To provide a geostationary orbit, the ring can be accelerated eastwards, causing the ring stations to remain over the same place on Earth

"It would eventually make the cost of taking payloads into orbit extremely cheap"

1 Space elevators
These would run down from stations positioned around the ring to Earth-based terminals. They could transport passengers and cargo to and from the orbital ring along cables made from carbon nanotubes.

2 Transport
A transport system inside or outside the ring could carry people around the globe and allow them to return to Earth down any of the space elevators carried by the ring stations.

3 Ring structure
The structure of the ring can be made from prefabricated inflatable modules.

4 Ring stations
A receiving and exit point for passengers and cargo, these can provide a base for living quarters, entertainment, scientific laboratories and construction.

© NASA; Adrian Mann

BIO+

Neil deGrasse Tyson

Tyson is the founder of the Department of Astrophysics at the American Museum of Natural History and director of the Hayden Planetarium at the Rose Centre for Earth and Space. He is an author and astrophysicist who regularly writes books and appears on our television screens. His appearances on various American TV shows, from *The Universe* to *The Colbert Report*, have brought the delights of space to the masses. He has also hosted a weekly podcast called *StarTalk* since 2009, which was turned into a spin-off TV show on National Geographic two years ago.

Neil deGrasse Tyson

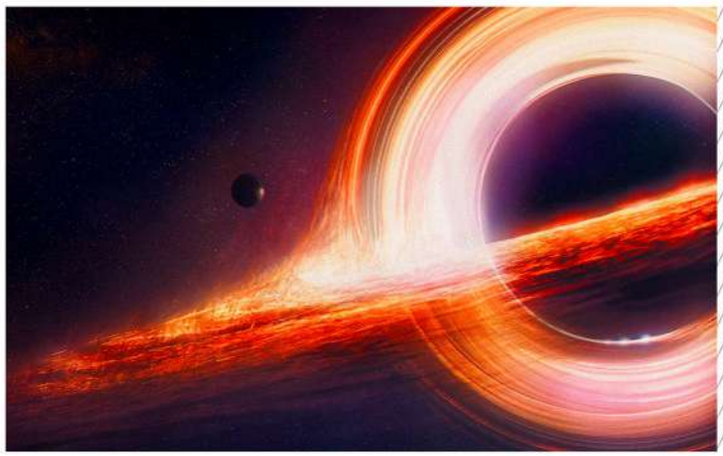
"It would be cool if we were some simulation"

The host of *StarTalk* has become one of the world's best known astrophysicists, popularising space and science for millions

Interviewed by David Crookes

You've gained a reputation for helping make science and space accessible to the wider population. How do you go about hitting the right spot for people – what do you think grabs their attention?
I've thought a lot about what might interest a disinterested person, and I've thought more about the impact of what I'm saying than you can possibly believe. I could say something off the cuff, and you'd say, "That's really cool, that's great; how have you just figured that out?" And I'd think, "No, I've thought about this and I've watched you react to things I've said – I know what you're going to find interesting." When I'm talking to people, I'm looking to see if they've raised their eyebrows or if they look bored or excited. I have a mental inventory of things that enchant and bore people and the things that people want to hear more of. I bring that to my lectures, books or *StarTalk*.

***StarTalk* has been around since 2009, but where did the idea come from, and what was your aim?**
Three of us started the concept. Myself and my co-executive producers Helen Matsos, who is a NASA astrobiologist, and David Gamble got together and realised there was an unserved population out there who, in our judgement, would enjoy science but didn't know that they would. We figured there was a population that does not buy science books or write on the calendar when a science program is coming on television – people who are kind of oblivious to it. And we thought we might be able to create a media product that would attract them. But in addition to that, we realised there was a demographic of people who are sure that they do not like science. Maybe they didn't do well in their science class and they spent the rest of their life avoiding it. We thought we might be able to reach to them as well. So *StarTalk* became a synthesis of pop culture, science and comedy.



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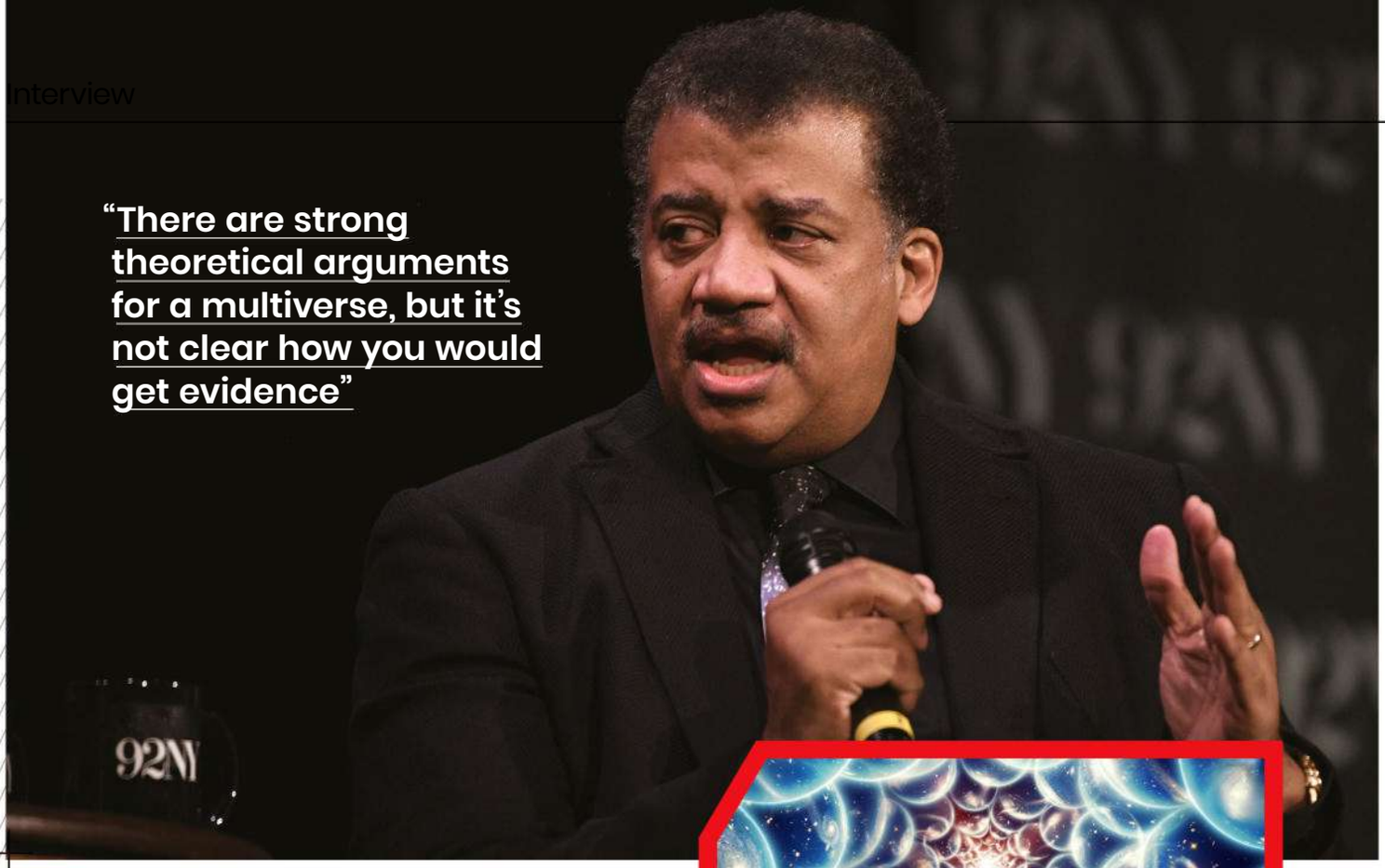
StarTalk delves into all kinds of space science, from planets to black holes



"There are strong theoretical arguments for a multiverse, but it's not clear how you would get evidence"

The weirder the universe is, the better for Tyson, but he claims what matters most are the things you can measure, detect and interact with

Multiverses could be out there, but Tyson isn't sure we could ever find definitive proof of their existence

Why did you go for that mix?
We realised that if you attach science to pop culture, you don't have to explain the pop culture parts. People know the famous actor, the famous singer or famous politician, and if they become my guests, and if my conversation with them explores science, then fans will follow them to the show and we get to expose people to science and show them how ubiquitous science is in their lives. We get to show them that it's even touching their favourite person. In the studio, I have my co-host, a professional comedian, and I typically bring in an academic on a particular subject that we cover in the interview with the pop culture person. The comedian is a valve of levity and the expert is a valve of gravity, and I control those valves in such a way so that the listener can get, in my judgement, the right balance of science, as it appears in everyday life. And you end up smiling along the way. This was an experiment, and we proposed this to the National Science Foundation and they agreed it would be interesting.

***StarTalk* has made the transition to television. How comfortable have the guests been about science, and have you been surprised at the science knowledge some of them have?**
It cuts two ways. I like to think of pop culture on *StarTalk* as the scaffold on which we place scientific topics, so my interviews are never to test the person to see how much science people know. That's not the point. What I want to know is how much science interest they might have, and if they don't have any interest, that becomes the challenge – for me to find ways that science has touched their lives. So with Bill Clinton, my favourite story was of him sitting around the table in the Oval Office with some important heads of state not agreeing on something. He said he had borrowed a Moon rock from NASA that he kept in the centre of the table, and every time there would be some conversational political impasse, he would point to the rock and say, "That rock is from the Moon." It gave everyone some cosmic perspective, and by playing the science card on everybody, they were playfully taken aback and could have a fresh conversation on what they needed to agree on. It's interesting to know that a head of state would do that.

You're not afraid of tackling some big ideas. We noticed recently that you said the universe could be a simulation. Why do you think that's the case?
I was slightly misquoted there and, you know, headlines take liberties and they become click bait for others if you're surfing the internet. What I said was that I think it would be really cool if we were some alien simulation, maybe someone's PhD thesis experiment. And then

© Getty: Tobias Roetsch

I wonder if the aliens would start getting bored and start to throw in things to disrupt what might be a peaceful, tranquil world. But there are serious philosophical questions and conversations about physics being conducted around this.

If we were in a simulation, do you think we'd be able to tell?
One of my favourite references to this was from a colleague of mine, Max Tegmark, a professor of astrophysics at the Massachusetts Institute of Technology. He said to imagine you're playing a game of Mario, and let's say you're in the game. You start taking measurements and you say, "Okay, if I jump, I jump this high, and the other characters don't jump as high as I do." So you start setting up laws of motion that apply inside the game, and eventually you might figure out all the laws of motion and that is your world. But is that anything different to what we're doing with our branches of science? We're trying to figure out the laws of nature.

Where do those laws come from? It's still a little bit of a mystery. Religious people would say god made the laws, but if you're more prone to secular accounts of things, you might ask are these coming about naturally or by hand, by someone who has created our world for their own entertainment? And then you get deeply philosophical and say if we are a simulation of some super-intelligent alien species, is that indistinguishable from the concept of god? That's another interesting topic to have a debate over a beer at a bar on, something to start arguing about, because everyone is going to have an opinion no matter how much or little research they have done on the subject.

Many similar debatable subjects have surfaced of late. Do you believe our universe is just one of an infinite number?
It's not a matter of what I believe in. I don't know that there is anything I believe in. That implies that I don't have any evidence for what I think is true. There are compelling arguments out there for why there might be a multiverse, and they are grounded in physics and sometimes quantum physics, and I sometimes find them compelling enough to invest more thought into what it might be like. The idea of multiple universes is a high-concept idea and people have a bit of armchair philosopher in them. It's fun to be able to tap that urge for people to want to think that way.

There's no hard and fast evidence of a multiverse?
No, there's no evidence. There are strong theoretical arguments for why we might have a multiverse, but it's not clear how you would get evidence. If you have no access to it, then what does it mean for you to hypothesise the existence of something that you will never detect? One of the things we've learned in science is what matters are the things that you can measure, detect and interact with. If you can't interact with it, does it even make sense to talk about it? But if you're intellectually active, you will talk about it.

The idea of the universe being a simulation is different to hologram theory, but do you think the hologram principle could hold some truth?
The hologram hypothesis is intriguing. You come up with it when you have an event horizon around a black hole, and I'm intrigued by that, this idea we are a record of something playing out in another way inside of an event horizon. What intrigues me from the point of physics is that certain other things we know are true want us to think this way about the event horizon and that there would be a hologram. Those are the interesting hypotheses in physics, where other things that are tested and you know to be true are logically required for other things to be true. I'm still following that space to see the next wave of development in it. But I'm all for it. The weirder the universe is, the better.

Do you think there is life out there that has tried to contact us?
I just wonder, not only whether we have been visited by extremely intelligent aliens, but whether we were simply not interesting enough to them because we're too stupid as a species. It's like, are worms interesting to you, unless they are your research speciality? Do you walk down the street, see a worm, pause and reflect? "I wonder what that worm is thinking? Let me see." No, you step on it or you walk by. It doesn't intrigue you. If plenty of life forms on Earth aren't interesting enough to stop you in your tracks, then why couldn't there be life forms vastly more intelligent than humans that see Earth as this boring place of DNA-based life and move on? We would do that, and we already do that with other forms of life on our own planet.

The other possibility is that they are so intelligent that they created a simulation – and this is, of course, the simulation hypothesis again, that they created us for their own entertainment. These are some things to talk about, perhaps. Whether or not they are grounded enough in scientific peer-reviewed papers, they are fun to talk about in a bar over a drink.

The idea that we are a record of something playing out in another way inside of an event horizon, known as the hologram hypothesis, intrigues Tyson

FOCUS ON

OBJECT HOTTER THAN THE SUN FOUND ORBITING A DISTANT STAR AT BREAKNECK SPEED

A weird celestial object that's blurring the line between planet and star has been uncovered

Reported by Joanna Thompson

A weird, super-hot celestial body is breaking records and challenging astronomers' understanding of the boundary between stars and planets. The object, called WD0032-317B, is a brown dwarf – a type of bright, gaseous 'protostar'. Brown dwarfs typically have a similar atmospheric composition to Jupiter but are around 13 to 80 times larger. At that mass, these objects begin to fuse hydrogen isotopes in their cores. However, they aren't quite massive enough to spark the kind of full self-sustaining stellar fusion that powers stars like our Sun – think of smouldering charcoal rather than a lit wood-fired oven.

Brown dwarfs usually burn at around 2,200 degrees Celsius (4,000 degrees Fahrenheit). That's fairly cool compared to most stars, whose surface temperatures reach about 3,700 degrees Celsius (6,700 degrees Fahrenheit). But WD0032-317B, which is 1,400 light years from Earth, is not like most brown dwarfs. In a paper published to the preprint database arXiv and accepted by the journal *Nature Astronomy*, researchers measured the object's surface temperature and found it was a blistering 7,700 degrees Celsius (13,900 degrees Fahrenheit). That's hot enough for the molecules in its atmosphere to fall apart into their component atoms. It's also several thousand degrees hotter than the surface of our Sun.

This should be impossible for a brown dwarf. But the researchers discovered that the object got an assist from the star it orbits. WD0032-317B is extremely close to its star, an ultra-hot white dwarf – so close that its year lasts just 2.3 hours. That proximity means WD0032-317B is tidally locked, with one side forever facing its star while the other faces away. Because of this, the brown dwarf is only superheated on one side. Even though its 'dayside' temperature skyrockets beyond our Sun, its 'nightside' is a comparatively balmy 1,000 to 2,700 degrees Celsius (1,900 to 4,900 degrees Fahrenheit). That's the most extreme temperature differential astronomers have measured on a substellar object. But these conditions won't last long – as its molecules continue to fall apart, the brown dwarf is being evaporated by its host star. Research on objects like WD0032-317B could help scientists understand how hot stars slowly consume their companions. It can also add to the growing body of knowledge around the conditions that stars need to ignite.

An illustration of a brown dwarf, a massive object that blurs the line between star and planet

© ASTRON/Danielle Futselaar

WILL ARTIFICIAL INTELLIGENCE CHANGE ASTRONOMY?

With computers growing smarter than ever, training them how to spot and categorise astronomical objects could lead to a plethora of breakthroughs

Reported by Colin Stuart

The world is currently in the grips of an artificial intelligence (AI) frenzy. Everyone is trying ChatGPT, AI stocks are surging to record highs and people are worried about whether machines are coming for their jobs. Yet astronomers have been using similar techniques to unlock the universe's secrets for decades. "It goes back over 30 years," says Chris Impey from the University of Arizona. In 1990, Impey's colleagues at the university's Steward Observatory used an artificial neural network (ANN) to both divide galaxies into groups based on their appearance and to distinguish between stars and galaxies in images of the sky. An ANN is fed a series of training images and is then set free to analyse new data. It looks for connections between data points and is based on a simplified version of the human brain.

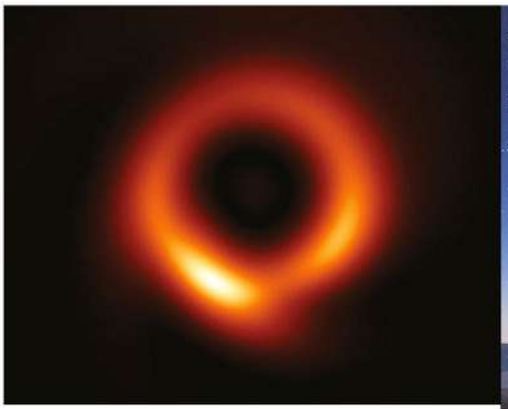
Classifying galaxies is intricate work. "Humans can't do it well enough," Impey says. Deciding whether a galaxy is a spiral or an elliptical may be fairly straightforward, but smaller details can be crucial. The galaxy may or may not have a bar structure in the centre, be asymmetrical or have distortions close to its outer edge. "That might tell you that the galaxy had an interaction with a neighbouring galaxy that has long since sailed off to a different part of space, but the distortion remains," Impey explains. "The distortions are subtle, a per cent or less." It's a bit like human scars. These small marks on our bodies tell a story about where we've been and the things that have happened to us.

© Getty

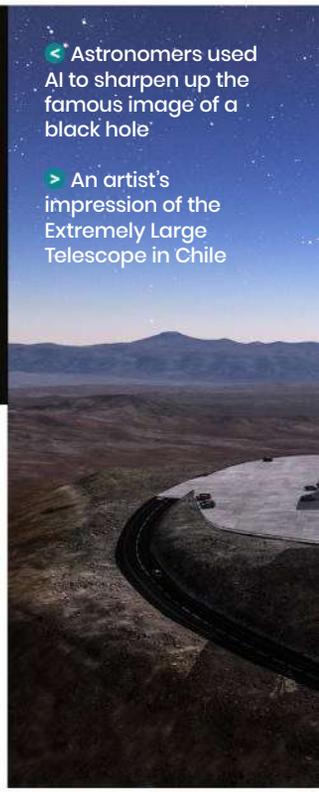
Galaxy classification software has even had an impact far beyond the realms of astronomy. A decade ago, astronomers at the University of Cambridge teamed up with oncologists to use their techniques to more accurately diagnose breast cancer. The software was adapted and taught to look for cancer cells instead of galaxies. Tests showed that the software was at least as accurate as a doctor looking down a microscope – and often far quicker, too.

Technology has come a long way since 1990, and today's computers are far superior. But then telescopes have also drastically improved. There's currently an arms race between the amount of data flooding in from all these observatories and the computing power needed to analyse it all. "We now have 10 to 12 metre [32 to 39 foot] telescopes that didn't exist a decade ago," Impey says, "and we're about to have 20 to 30 metre [65 to 98 foot] telescopes in the next six years." The 30-metre Extremely Large Telescope, for example, is due to see first light in 2028. It has around 250 times the light-gathering area of the Hubble Space Telescope and will provide images 16 times sharper.

The upcoming Vera C. Rubin Observatory, due to start observing next summer, will generate 20 terabytes of data every single night. In just ten nights it will create as much data as is contained in all the printed material in the world. Then there are telescopes that don't see in visible light. Construction has already started on the Square Kilometre Array (SKA), a vast group of radio dishes acting as one giant telescope. Based in both South Africa and Australia, when the SKA is finished in 2028 it will create about ten times more data than current annual global internet traffic and will survey the sky 10,000 times faster than any of its predecessors. "The surveys that are coming



< Astronomers used AI to sharpen up the famous image of a black hole



> An artist's impression of the Extremely Large Telescope in Chile

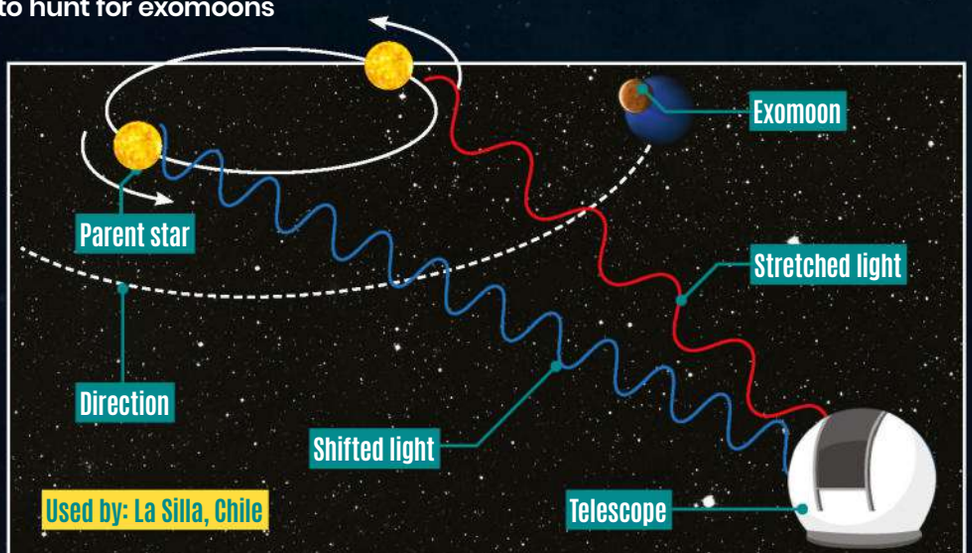
HOW TO FIND AN ALIEN MOON

The different methods being used to hunt for exomoons

Transit timing effect

The transit timing method works by measuring a change in the regular transit of a planet. Essentially, as a planet swings around a star, if there are other objects in its vicinity then it can affect how often a transit is completed. This often indicates the presence of other planets in the system, but in theory the method could be used to hunt for large exomoons as well, revealing their tug on their parent planets. It's hard to distinguish between an exoplanet and an exomoon via this method, though, so it might be difficult to make a discovery with it.

Used by: Kepler



Radial velocity method

When an exoplanet orbits a star, its gravity can cause a tug on the star, making it noticeable. The star's spectrum of light is shifted to the blue end of the spectrum if it's coming towards us, and the red end if it's going away from us. Using this method, some characteristics of the parent planet can be determined. Like the transit timing method, it's thought that the same principle could be applied to exomoons, noticing their effect on a planet. Again, though, the effect is so small that it will be hard to find exomoons using this method.

Astrometry
The pull of a planet can also cause the star to change position in the night sky. These wiggles are almost imperceptibly tiny and require incredibly precise observations to tease out.

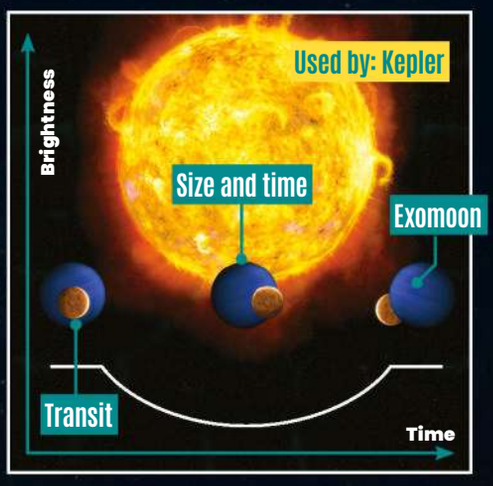
Pulsar timing
The very first exoplanets we discovered were seen orbiting a dead star called a pulsar. Pulsars spin incredibly rapidly and spit out pulses of radiation – hence the name. These pulses are usually impeccably spaced, but an orbiting planet can throw off the rhythm.

Direct imaging
Occasionally, it's possible to see an alien planet directly, particularly if it's a new planet that's emitting a lot of heat shortly after its formation. It also helps if the planet orbits far from its star.

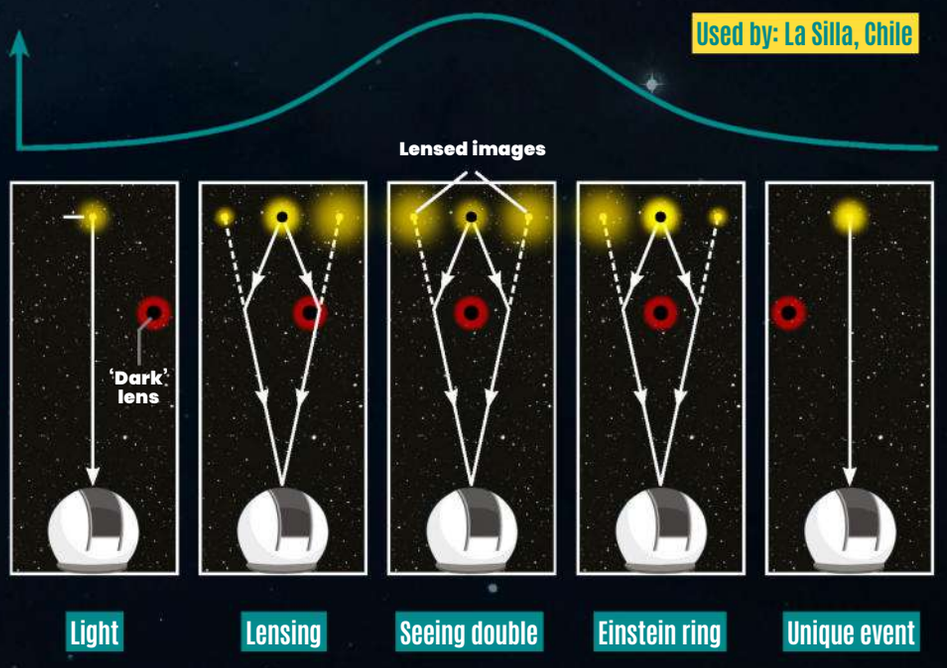
will take us from tens of millions of galaxies to hundreds of millions or even billions of galaxies," Impey says. There's just no way humans could comb through that much data. We're going to need the latest advances in AI to help decipher it all.

Galaxy classification, formation and evolution is far from the only area of astronomy that AI is extremely useful, though. One of the biggest mysteries of modern astronomy is what's holding everything together. Astronomers suspect that a shadowy substance called dark matter helps glue galaxies and clusters of galaxies, but we still don't know what it actually is. The SKA will help astronomers map dark matter, but another way to chart its distribution is to use an effect called weak gravitational lensing. The gravitational pull of dark matter distorts light as it travels through the universe. This can be spotted by looking at large samples of galaxies. "You can't do it by eye or by hand," Impey says. The changes can be as subtle as 0.1 per cent. Again, we need AI. Similarly, small changes are a big part of exoplanet

Transit method
Many exoplanets have been found using the transit method. As a planet periodically orbits its star, it causes a dip in the star's light – or flux – if it crosses our line of sight. Measuring this dip, we can then determine the orbital period, and even the size of the planet. The same method could also be used for exomoons, noticing the combined dip produced by both the moon and its planet. Indeed, as the moon will be moving around the planet, it may block a different amount of light depending on its position, giving us a key insight.



Microlensing
Microlensing events are one of those rare cosmic phenomena that remind you how awesome the universe is. Gravitational microlensing is the result of an object in the universe magnifying a more distant object. For example, an intermediate star can boost the light of a more distant galaxy, although any given event will occur only once. If the intermediate star has a planet orbiting it, then the effect is altered, and the presence of the planet can be deduced. More recently it's been suggested that this same method could be used to detect exomoons.



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science and the hunt for a second Earth. One of the ways astronomers find alien planets in the first place is through the so-called 'transit technique'. The planets are too small, too dim and too far away to see directly. However, they sometimes pass in front of – or transit – their host stars. We see the star get temporarily dimmer as a result. The transit of a Jupiter-sized planet will lead to a mere one per cent drop in brightness in a Sun-like star. For another Earth, which is considerably smaller, it is just 0.01 per cent.

"We want to squeeze as much out of the data as possible," says Impey. "The slope of the dip is telling you something about the atmosphere of the planet." That's because the atmosphere is the first thing to pass in front of a star and the last thing to leave it. Planetary rings like those around Saturn could also have a similar effect. These effects are so subtle that we need AI to pull them out of the mess of data.

There might also be something else hidden in that jumble of zeros and ones. "One of the holy grails of exoplanet work is to find an exomoon," Impey says. There are two ways an alien moon could show up. "You could see a dip on top of a dip," Impey says. A tiny one for the moon, followed by a bigger one for the planet. The gravity of a moon will also affect the timing of its planet's transits. They could begin slightly later or earlier on successive orbits as a result. "You'd be hard pushed to see any of this without machine learning," Impey says. Not that machine learning is a panacea. It all comes down to the data you feed the AI in the first place. "It's only as good as the training data, and to do good training you need a good model," Impey says. For example, you need to feed the algorithms accurate models of what an exomoon transit might look like, even though we've never actually seen one.

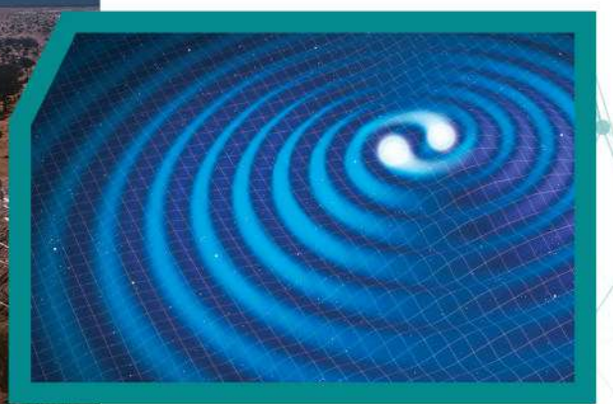
The recent furore around ChatGPT has shown that sometimes AI hallucinates and spits out things that simply don't exist. Radio host Mark Walters is suing OpenAI, the company behind ChatGPT, for defamation because the generative AI tool falsely accused him of embezzling money. Similar hallucinations can happen when using AI in astronomy. "You're working at the limit of detection," Impey says. "It's possible to see something that isn't there." Astronomical observations are plagued by noise – random contributions from various sources that affect a measurement. AI could latch onto these fluctuations and label them an important discovery. Just like scientists repeat their non-AI experiments for increased reliability, it's important that astronomers run several different AI models to ensure that what they're seeing isn't a ghost in the machine.

Along with ChatGPT, OpenAI has also introduced a text-to-image generator called DALL·E 2. In astronomy, AI can help draw out more information from existing images. One of the most famous astronomical images of recent times is the first picture of a black hole, revealed in 2019 by the team behind the Event Horizon Telescope. Earlier this year, a team led by Lia Medeiros used AI to enhance the photograph and show that the black hole was larger than originally calculated.

Machine learning can help astronomers discover more about colliding black holes, too. Einstein's general theory of relativity predicted the existence of gravitational waves – ripples in the very fabric of the universe itself. The first gravitational waves ever detected were created by a pair of colliding black holes. The waves act as a super-accurate pair of scales, allowing astronomers to calculate the masses of the black holes involved. In 2021 a team led by Hunter Gabbard announced that they had devised a machine-learning technique that could calculate the black holes' masses a million times more quickly than current state-of-the-art computers.

Colliding black holes are also a useful test of general relativity itself. Scientists have

An artist's impression of the Square Kilometre Array's central core of antennae



Colliding black holes create gravitational waves, which can be a test of general relativity

HUBBLE'S TUNING-FORK CLASSIFICATION SYSTEM

1 Sc: open spiral
These contain more Population I stars and interstellar gas. They have loosely wound arms and a small central bulge. These consist of ten per cent gas and dust, compared with two per cent in Sa spirals.

2 Sb: intermediate spiral
Found between Sa and Sc, intermediate is the most common form of spiral galaxy. All spirals are rich in gas and dust and contain young Population I stars, along with older Population II stars.

3 Sa: spiral
The arms are tightly wound, with a bright central bulge and small amounts of interstellar gas. The S refers to this being a spiral and the lowercase letter refers to how tightly wound the arms are.

4 S0: lenticular
This is lenticular shaped with a prominent central bulge, but has no spiral arms. They are like ellipticals because they tend to contain old stars and have less gas and dust than spirals.

5 SBa: barred spiral
The B designates that the galaxy has a bar of stars at its centre that the spiral arms wind away from. Again, the lowercase letter refers to how tightly wound the spiral arms are.

6 SBb: intermediate barred spiral
Our Milky Way galaxy is thought to be of this type.

7 SBc: open barred spiral
The least defined bar and a looser structure.

8 E0: spherical
The roundest looking galaxies. This corresponds to the physical structure of the galaxy; the rest of the E-type galaxies refer to how they look from Earth rather than their actual structure.

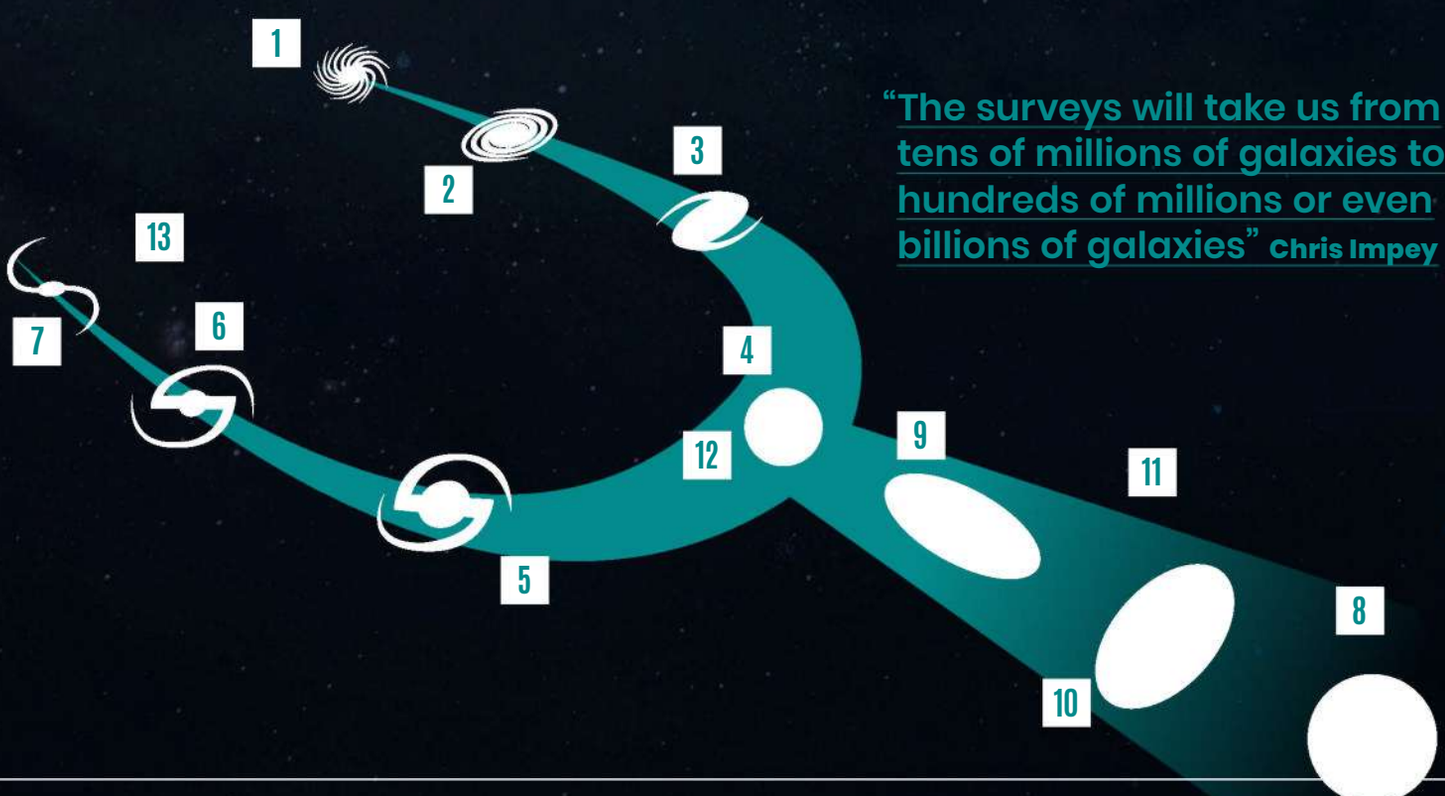
9 E5 and E7: elongated ellipticals
The most flattened galaxies. Elliptical galaxies tend to contain old stars and are loosely structured, indicating they were formed before spiral galaxies.

10 E3: elliptical
Ellipticals are given higher numbers according to how flat they look. The E prefix refers to this being an elliptical galaxy and the number refers to how flat the galaxy is.

11 Elliptical galaxies
Rugby-ball-shaped blobs of stars that don't rotate very quickly. The number after the E is a measure of the galaxy's shape. An E0 is spherical, whereas an E7 is more cigar-shaped.

12 Lenticular galaxies
These are designated as S0. Lenticulars are part way between elliptical galaxies and spirals. They have a disc, but don't have distinctive spiral arms.

13 Spiral galaxies
Galaxies with swirling arms. They're flat and rotate faster than ellipticals. The spirals create two branches on the tuning fork. The SBs have a bar structure in their centres.



"The surveys will take us from tens of millions of galaxies to hundreds of millions or even billions of galaxies" **Chris Impey**

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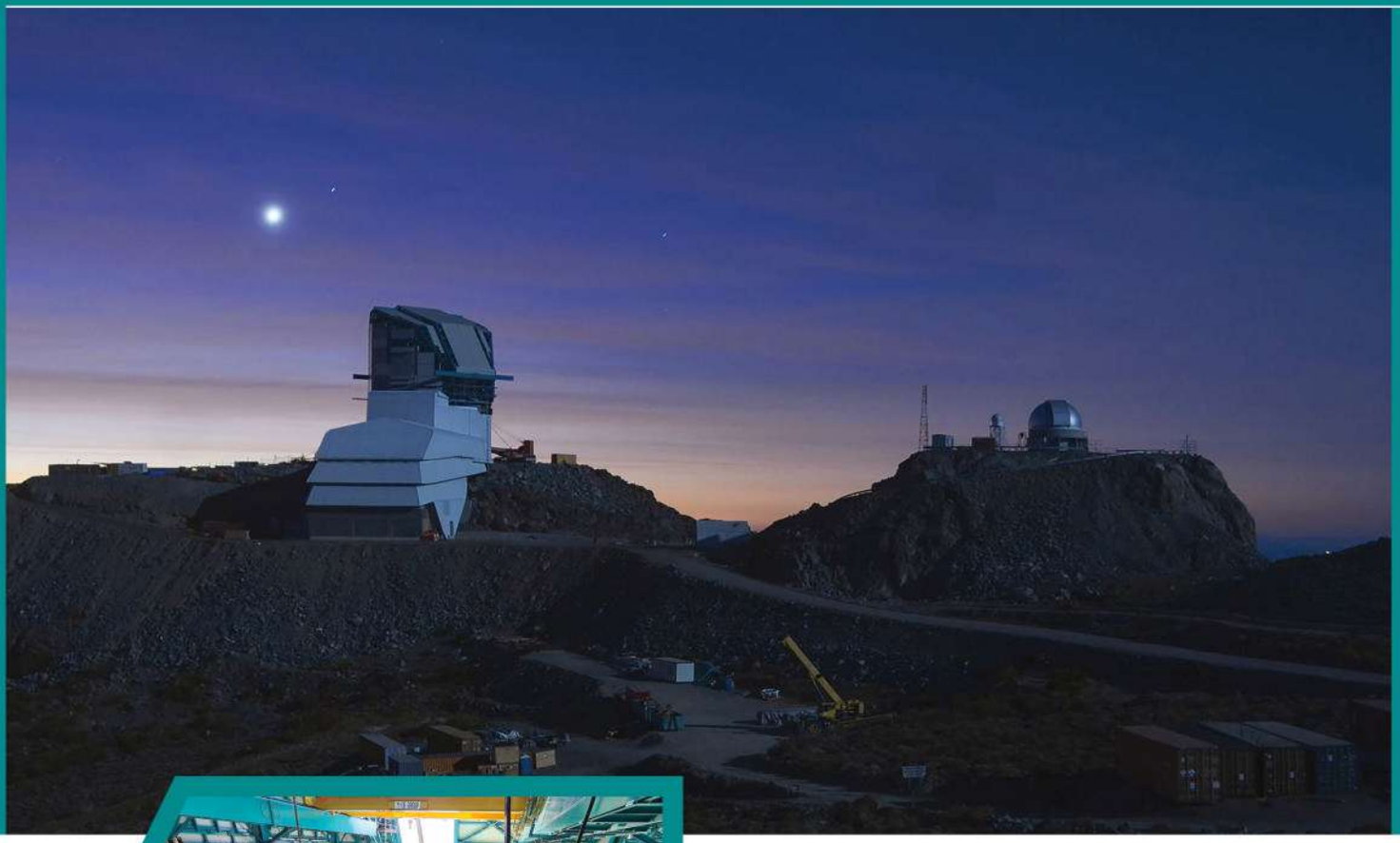

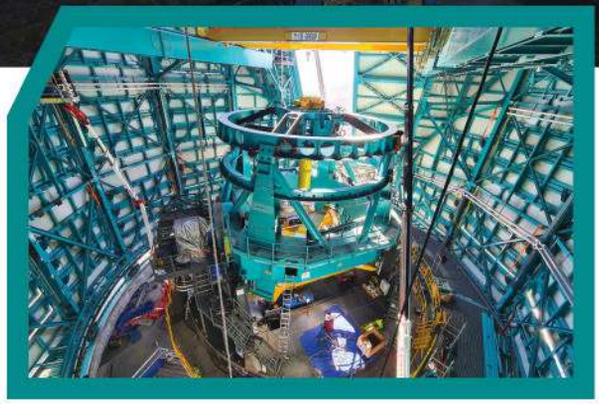

Telescopes are getting so big and powerful that we need help to sift through the data

The 8.4-metre Simonyi Survey Telescope at Vera C. Rubin Observatory

long searched for a so-called 'theory of everything' - a single set of rules that describes the universe. General relativity originally replaced Isaac Newton's theory of gravity when we realised there were situations when the latter broke down. Seeing if and where general relativity cracks could open the door to the theory of everything.

Then there's the search for things that we don't know about and brand-new discoveries. "That's the frontier of machine learning," Impey says. He points towards the interstellar interloper 'Oumuamua as an example. It entered our Solar System from another star system and shocked astronomers with its peculiar cigar-like shape. It's not something we'd have designed AI to look for, so we need to work out how the technology can help us spot things not explained by any current theory.

Nor do you always have to make new observations to arrive at a significant breakthrough. Around 25,000 papers are published on astronomy and astrophysics every year. You'd have to read one every 20 minutes for the whole week without sleeping to get through them all, which just isn't possible. That's not to mention all the research going back decades. "Everyone struggles to keep up," Impey says. A project called astroBERT is using machine learning to improve the ways researchers can search through and make connections between existing parts of astronomical literature.

As the example of using galactic software for cancer diagnoses illustrates, sometimes the most useful connections are between astronomy and another field of research. Equally, a model already used in biology could be just the thing an astronomer needs to solve their own problem. Machine learning and language models could trawl multitudes of research in a fraction of the time it would take humans, prompting them to read up on things they would never have thought to even look at.

Taken together, these breakthroughs mean that we are on the verge of a step change in our understanding of the universe. We've come a long way in the four centuries since astronomers like Galileo pointed primitive telescopes at the sky. Modern telescopes are getting so big that we need a helping hand, and AI could be just the tool we need to unlock some of the universe's deepest secrets.

Colin Stuart
Astronomer and space science writer
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.

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FOCUS ON

COSMIC 'SANDWICH' THEORY COULD EXPLAIN HOW SMALLER PLANETS ARE FORMED

Sandwiched planet formation may arise as the result of gas and dust being squeezed between large planets

Reported by Robert Lea

Smaller planets might be born when gas and dust are squeezed between larger worlds, like the filling in a cosmic sandwich. The newly suggested process, dubbed 'sandwiched planet formation', would occur in the massive discs of planet-birthing gas and dust that swirl around stars in their infancy. Around 4.5 billion years ago, the Solar System itself would have existed as one such disc around the infant Sun, from which the planets arose.

This new theory of planet birth was developed by researchers at the University of Warwick. According to sandwiched planet formation, two large planets already present in the protoplanetary disc would restrict the flow of dust inwards through the flattened cloud of gas and dust. This results in matter collecting between the planets, with dense patches of the protoplanetary disc collapsing to birth planets. This gathering of gas and dust between the original two large planets would then form a middle planet smaller than its two outer companions. The theory put forward by the team still needs to be confirmed, but if it is, it could explain how smaller planets like Mars are born.

It could even account for the creation of planets like Uranus, which themselves are quite large, but are still surrounded by even more massive worlds. "In the last decade, observations have revealed that rings and gaps exist in protoplanetary discs. The gaps are where we expect planets to be, and we know from theory work that planets cause dust rings to form just exterior to them," University of Warwick associate professor Farzana Meru said. "What exactly is happening in those rings poses an important question to astronomers around the world."

Meru explained that sandwiched planet formation differs considerably from currently favoured models of planet formation that see planets form in sequence – starting at the inside of protoplanetary discs before moving to their outer regions – in addition to suggesting planets should get more massive further out in the disc. "What is also really interesting is that there are examples that we have found from exoplanet observations that actually show this sandwiched planet architecture – here the middle planet is less massive than its neighbours; it's a reasonable proportion of the systems, too," Meru continued.

The University of Warwick scientist highlighted the fact that the field of planet formation has undergone considerable growth over the last ten years. This is partially thanks to high-resolution images of protoplanetary discs that have been collected by sophisticated telescopes like the Atacama Large Millimeter/submillimeter Array (ALMA), a system of 66 radio antennae located in the Atacama Desert of northern Chile that form a single radio telescope.

The growth of planet formation as a field of science has allowed scientists to start suggesting new 'out there' models of planet formation based on the evidence they see in both protoplanetary disc images and from observations of fully formed exoplanets. "These images have given us clues about how planets form and evolve," Meru concluded.

1 A very large collection
ALMA is made up of 66 dishes. Each one of the dishes gathers faint radio waves from space.

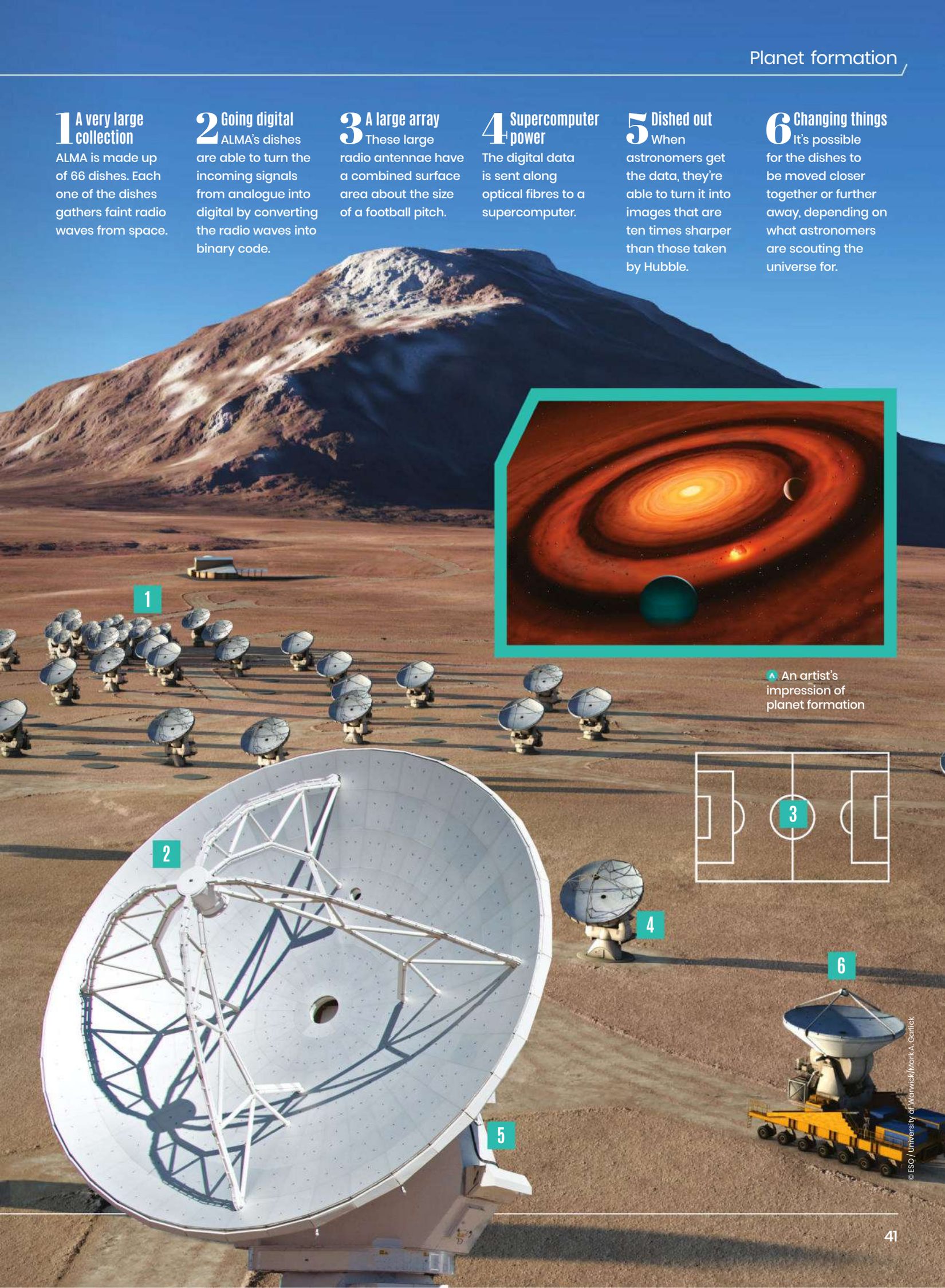
2 Going digital
ALMA's dishes are able to turn the incoming signals from analogue into digital by converting the radio waves into binary code.

3 A large array
These large radio antennae have a combined surface area about the size of a football pitch.

4 Supercomputer power
The digital data is sent along optical fibres to a supercomputer.

5 Dished out
When astronomers get the data, they're able to turn it into images that are ten times sharper than those taken by Hubble.

6 Changing things
It's possible for the dishes to be moved closer together or further away, depending on what astronomers are scouting the universe for.



An artist's impression of planet formation

© ESO / University of Warwick/Mark A. Garlick

PLANET PROFILE

NEPTUNE

The isolated azure ice giant remains a relative mystery

Neptune was the first planet to have its existence predicted by mathematical calculations before it was actually seen through a telescope on 23 September 1846. Irregularities in the orbit of Uranus led French astronomer Alexis Bouvard to suggest that the gravitational pull from another celestial body was responsible. German astronomer Johann Galle then relied on subsequent calculations to help spot Neptune. Astronomer Galileo Galilei had sketched the planet, but he mistook it for a star due to its slow motion.

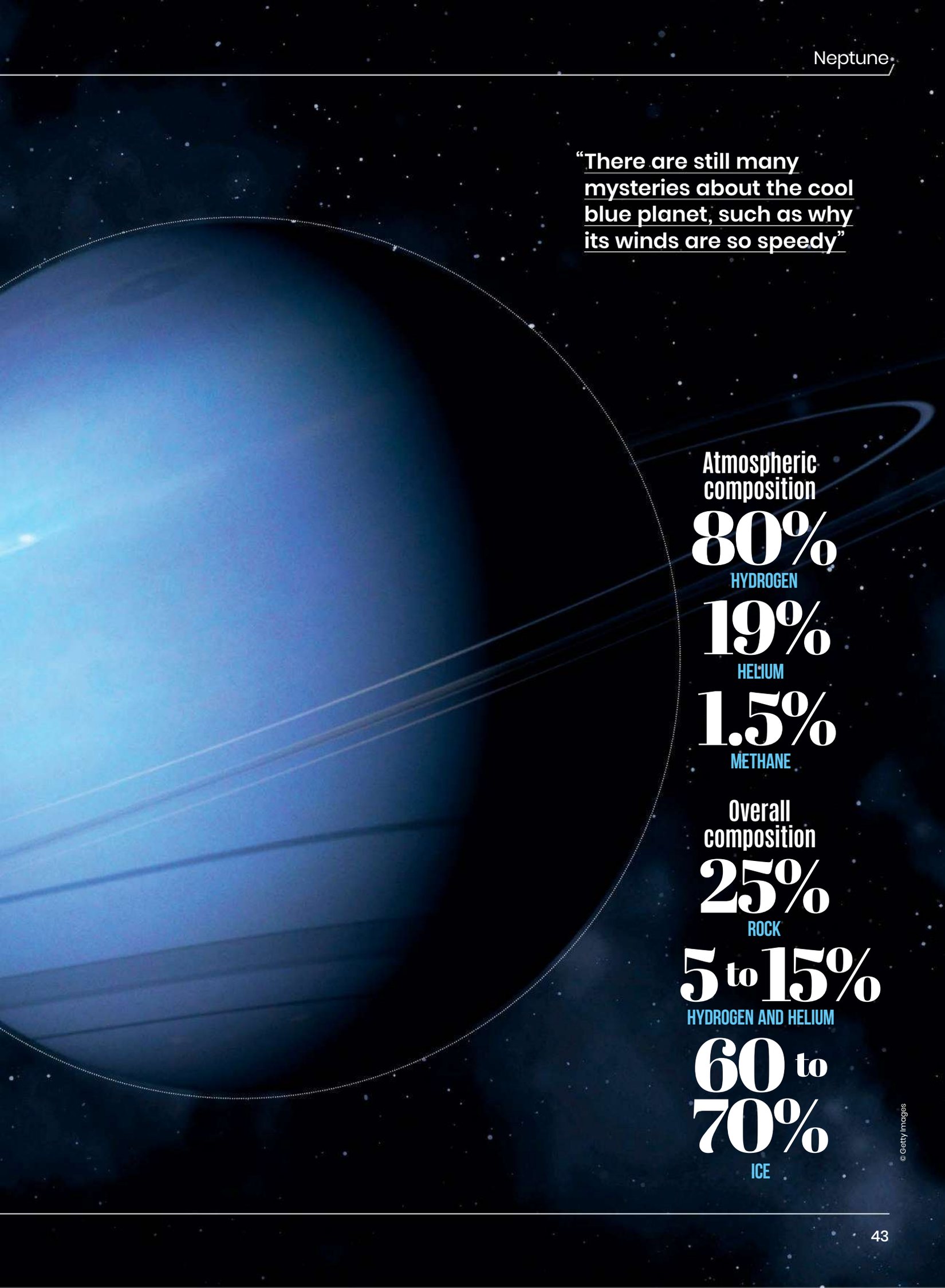
Only one mission has flown by Neptune – Voyager 2 in August 1989 – meaning that astronomers have done most studies using ground-based telescopes. There are still many mysteries about the cool blue planet, such as why its winds are so speedy and why its magnetic field is offset. While Neptune is of interest because it's in our Solar System, astronomers are also interested in learning more about the planet to assist with exoplanet studies. Specifically, some astronomers are interested in learning about the habitability of worlds that are somewhat bigger than Earth.

Those closer to Earth's size are called 'super-Earths', while those that are closer to Neptune's are 'mini-Neptunes'. However, there's some debate about those terms, given that today's telescope technology doesn't make it possible to view how much atmosphere is on those planet types, making it difficult to make a distinction.

Like Earth, Neptune has a rocky core, but it has a much thicker atmosphere that prohibits the existence of life as we know it. Astronomers are still trying to figure out at what point a planet becomes so large that it may pick up a lot of gas from the area, making it difficult or impossible for life to exist. Neptune's cloud cover has an especially vivid-blue tint that is partly due to an as-yet-unidentified compound and the result of the absorption of red light by methane in the planet's mostly hydrogen-helium atmosphere. Photos of Neptune reveal a blue planet, and it's often dubbed an ice giant since it possesses a thick, slushy fluid mix of water, ammonia and methane ices under its atmosphere. It's roughly 17 times Earth's mass and nearly 58 times its volume. Neptune's rocky core alone is thought to be roughly equal to Earth's mass.

Despite its great distance from the Sun, which means it gets little sunlight to help warm and drive its atmosphere, Neptune's winds can reach up to 2,400 kilometres (1,500 miles) per hour – the fastest detected yet in the Solar System. These winds were linked with a large, dark storm that Voyager 2 tracked in Neptune's southern hemisphere in 1989. This oval-shaped counterclockwise-spinning 'Great Dark Spot' was large enough to contain the entire Earth, and moved westward at nearly 1,200 kilometres (750 miles) per hour. This storm seemed to have vanished when the Hubble Space Telescope later searched for it. Hubble has also revealed the appearance and then fading of other dark spots over the past decade, and a new one was observed in 2016. It doesn't look like Neptune is finished with surprising scientists just yet.

A Voyager 2 view of Neptune



"There are still many mysteries about the cool blue planet, such as why its winds are so speedy"

Atmospheric composition

80%
HYDROGEN

19%
HELIUM

1.5%
METHANE

Overall composition

25%
ROCK

5 to 15%
HYDROGEN AND HELIUM

60 to 70%
ICE

© GettyImages

NEWS FROM NEPTUNE

A dark storm on Neptune mysteriously reversed

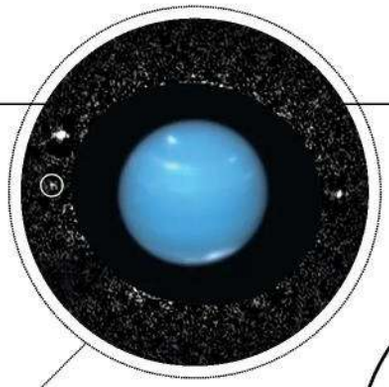
A dark storm on Neptune abruptly switched direction, puzzling astronomers. Hubble first spotted the vortex in 2018. A year later, the storm began drifting towards Neptune's equator, following the path of several storms before it. Usually these dark spots on Neptune live for a few years before either vanishing or fading away. However, the storm mysteriously stopped moving south and made a sharp U-turn, drifting back northwards. At the same time, astronomers spotted a second smaller dark spot on the planet. They theorise that this smaller 'cousin' may be a piece of the original vortex that broke off and drifted away.

Neptune's smallest moon has a violent past

Hippocamp is believed to have a diameter of about 34 kilometres (21 miles). The tiny moon circles in the same general neighbourhood as six moons discovered by Voyager 2. Hippocamp is just 12,000 kilometres (7,450 miles) away from the largest and outermost of these other six, Proteus. Like Earth's Moon, Proteus has been slowly spiralling away from its parent planet. So has Hippocamp, though at a much slower rate. About 4 billion years ago, Proteus was probably right next to Hippocamp and would have gobbled the smaller moon up, so scientists believe that Hippocamp was once part of its larger neighbour.

Triton has a rare kind of ice

Neptune's largest moon Triton boasts an uncommon icy mixture of carbon monoxide and nitrogen, which could help astronomers better understand the conditions of other distant alien worlds. Using the Gemini Observatory in Chile and a high-resolution spectrograph called the Immersion Grating Infrared Spectrometer (IGRINS), a visiting instrument for Gemini, astronomers detected a distinct infrared signature on Triton, revealing a mixture of carbon monoxide and nitrogen frozen as solid ice. This finding helps explain seasonal atmospheric changes on Triton and how material is transported across the moon's surface via geysers.



VISITING NEPTUNE

- **Date:** 23 September 1846
  Activity: Astronomer Johann Galle viewed Neptune through a telescope for the first time.
- **Date:** 10 October 1846
  Activity: Neptune's largest moon Triton was discovered.
- **Date:** 25 August 1989
  Activity: NASA's Voyager 2 flew by Neptune, coming within just 3,000 kilometres (1,860 miles) of the planet's north pole.
- **Date:** 1 July 2013
  Activity: Neptune's smallest moon, Hippocamp, was discovered during an analysis of older Hubble images.
- **Date:** 8 October 2013
  Activity: Neptune's 'lost' moon Naiad was spotted for the first time in 20 years. The tiny moon had remained unseen since the cameras on NASA's Voyager 2 spacecraft first discovered it in 1989.

Neptune seen in infrared by the James Webb Space Telescope

NEPTUNE BY NUMBERS

165
Earth years
How long Neptune takes to complete an orbit of the Sun

14
The number of known moons of Neptune

-214°C
Average temperature on Neptune in degrees Celsius

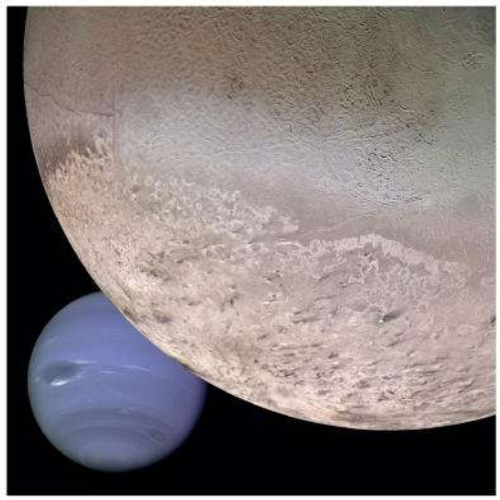
4.5 billion kilometres
How far Neptune is from our Sun

7.6 billion square kilometres
The surface area of Neptune

27x
How many times more powerful Neptune's magnetic field is than Earth's

28.3 degrees
The angle of Neptune's tilt as it orbits the Sun

WHEN TRITON CRASHED THE PARTY AT NEPTUNE



Neptune's original satellites may have been destroyed when its largest moon, Triton, entered the picture. The massive moon may have tossed some of the original satellites into the ice giant, kicked others out of orbit and swallowed up the rest, creating a new family that doesn't look much like those of the other giant planets.

For years scientists have suspected that Triton wasn't part of Neptune's original collection of moons. The massive moon has a backwards orbit and makes up over 99 per cent of all the mass orbiting the planet. They think it's a captured object whose orbit was circularised by debris discs created by impacts. The moons of Jupiter, Saturn and Uranus are all well-behaved when compared with Neptune's. The other three gas giants have a wealth of satellites – Jupiter has at least 80 moons to Neptune's 14 – travelling in nearly circular paths around their equators. While Triton's path is circular, it travels backwards compared with Neptune's rotation, and spins backwards, too.

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INSTANT EXPERT

WHAT CAN WE DO WITH A CAPTURED ASTEROID?

Asteroids could provide us with rare resources

Asteroids have more than enough gold, and other precious metals, to provide a few lifetimes' worth of fortunes. But there are plenty of other reasons asteroids are valuable. But how do we get these metals from faraway asteroids? Perhaps the best way is to bring the space rocks to Earth. Most of the metals we use in our everyday lives are buried deep within our planet. And we mean deep: when the young Earth was still molten, almost all of the heavy metals sank to the core, which is pretty hard to get to. The accessible veins of gold, zinc, platinum and other valuable metals instead came from later asteroid impacts on Earth's surface.

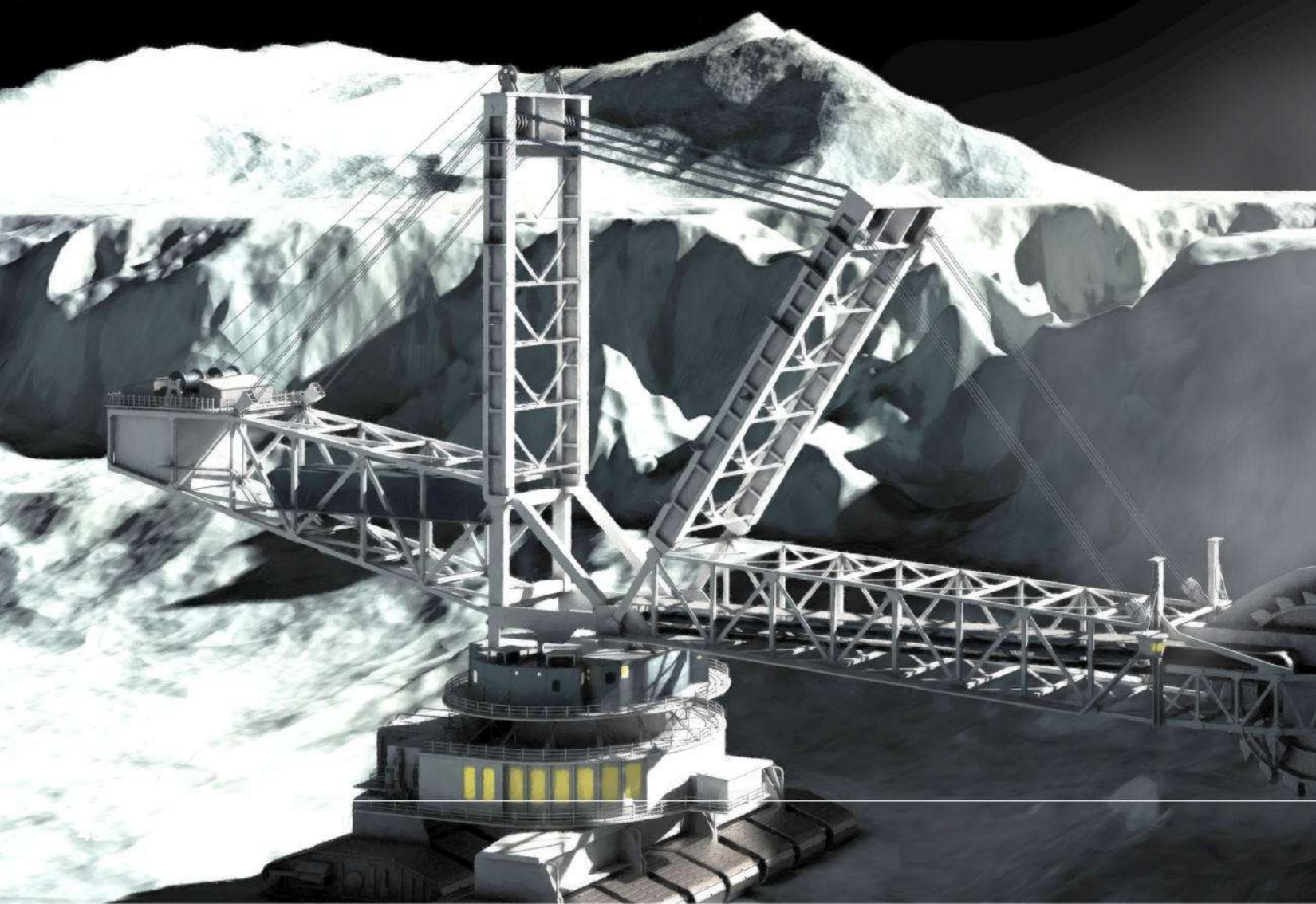
Those asteroids are the fragmented remains of almost-planets, but they contain all the same mixtures of elements as their larger planetary cousins – and you don't have to dig down into their cores to get it. But the main problem with asteroids is that they are far away.

To launch from Earth's surface and go into orbit, a rocket needs to change its velocity from zero to eight kilometres (five miles) per second. To rendezvous with an average asteroid, the rocket has to change its velocity by another 5.5 kilometres (3.4 miles) per second. That requires almost as much fuel as the launch itself, which the rocket would have to carry as dead weight, adding to the already-high cost of trying to set up a remote mining operation in the first place. And once the asteroid was mined, asteroid prospectors would be faced with a difficult choice: they could try to refine the ore right there on the asteroid, which would entail setting up an entire refining facility, or ship the raw ore back to Earth, with all the waste that would involve.

BIO

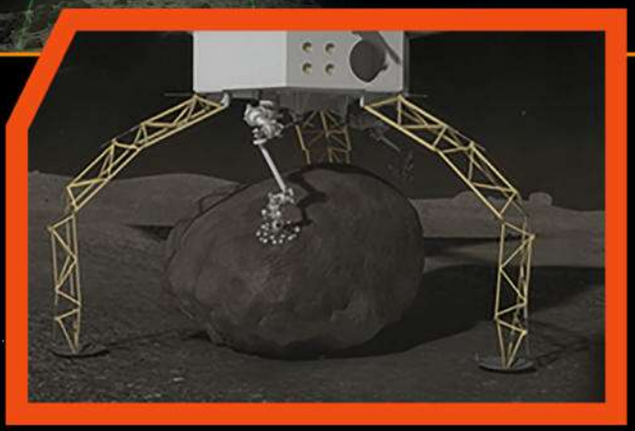
PAUL M. SUTTER

Sutter is a research professor in astrophysics at the Institute for Advanced Computational Science at Stony Brook University and a guest researcher at the Flatiron Institute in New York City. He is also the author of two books: *Your Place in the Universe* and *How to Die in Space*.



Bringing home the goods

Instead of trying to mine a distant asteroid, how about we bring the asteroid to Earth? NASA's ill-fated Asteroid Redirect Mission (ARM) was an attempt to do just that. The goal of the mission was to grab a four-metre (13-foot) boulder from a nearby asteroid and return it to cislunar space – between the orbits of Earth and the Moon – where we could then study it at our leisure. To move the boulder, ARM would use solar electric propulsion, with solar panels absorbing sunlight and converting it into electricity. That electricity would power an ion engine. It wouldn't be fast, but it would be efficient – and it would eventually get the job done. Unfortunately, in 2017 NASA cancelled ARM. Some of the critical technologies wound up in other projects, like the mission to the asteroid Bennu, and NASA continues to investigate and use ion engines.



Within arms reach

A recent study found a dozen potential asteroids, ranging from 2.0 to 20 metres (6.6 to 66 feet) across, that could be brought into near-Earth orbit with a change in velocity of less than 500 metres (1,640 feet) per second. The solar electric propulsion schemes cooked up for ARM would be perfectly capable of that, although it would take a while. Once an asteroid is in near-Earth space, many of the difficulties of asteroid mining are significantly reduced. A cislunar asteroid would be much easier to study and much easier to test different mining strategies on.

16 Psyche

The asteroid 16 Psyche contains roughly 10 billion billion kilograms of nickel and iron, which are used in everything from reinforced concrete to mobile phones. If we maintain our current consumption of nickel and iron, 16 Psyche alone could supply our industrial needs for several million years.

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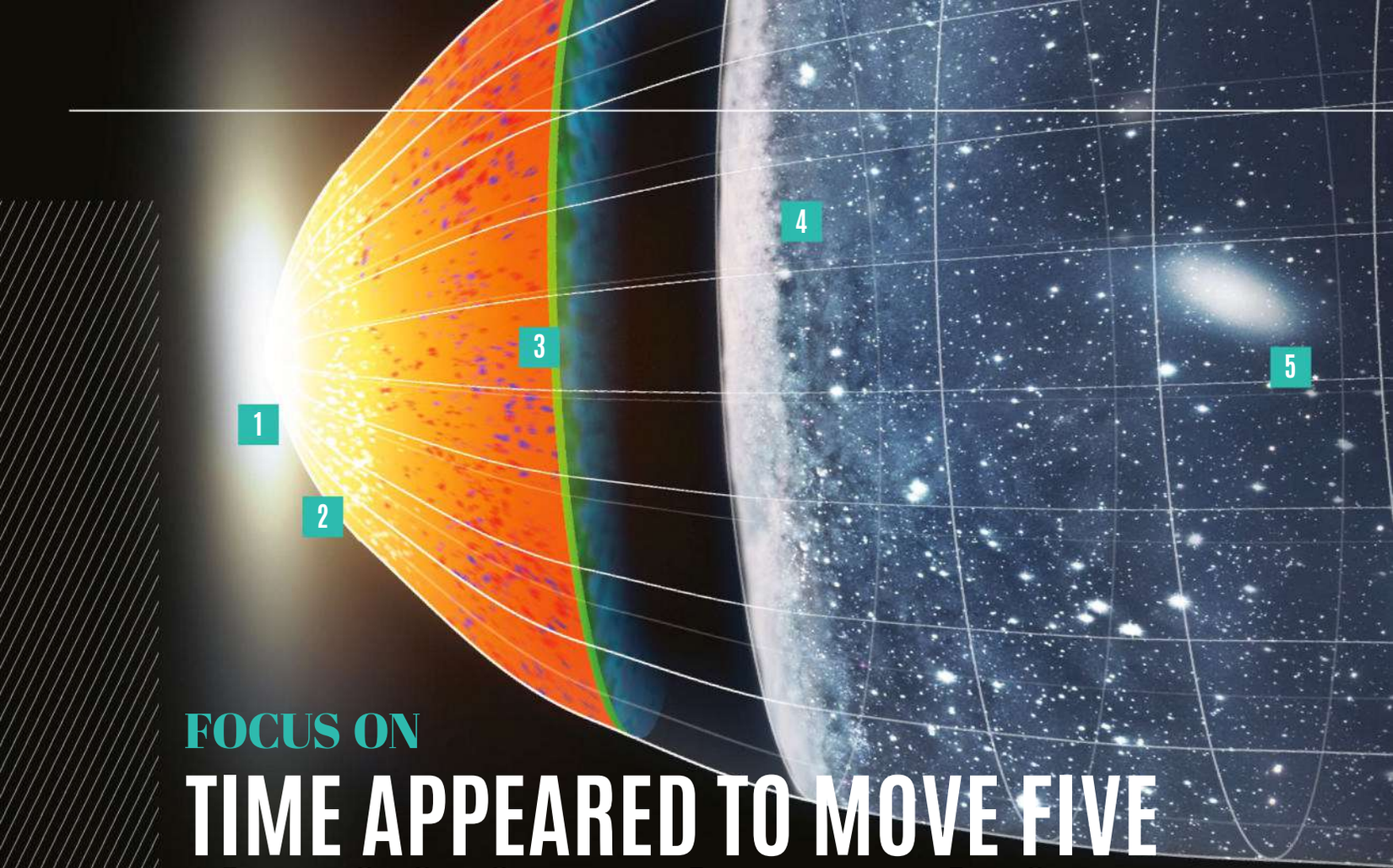


FOCUS ON

TIME APPEARED TO MOVE FIVE TIMES SLOWER IN THE FIRST BILLION YEARS AFTER THE BIG BANG

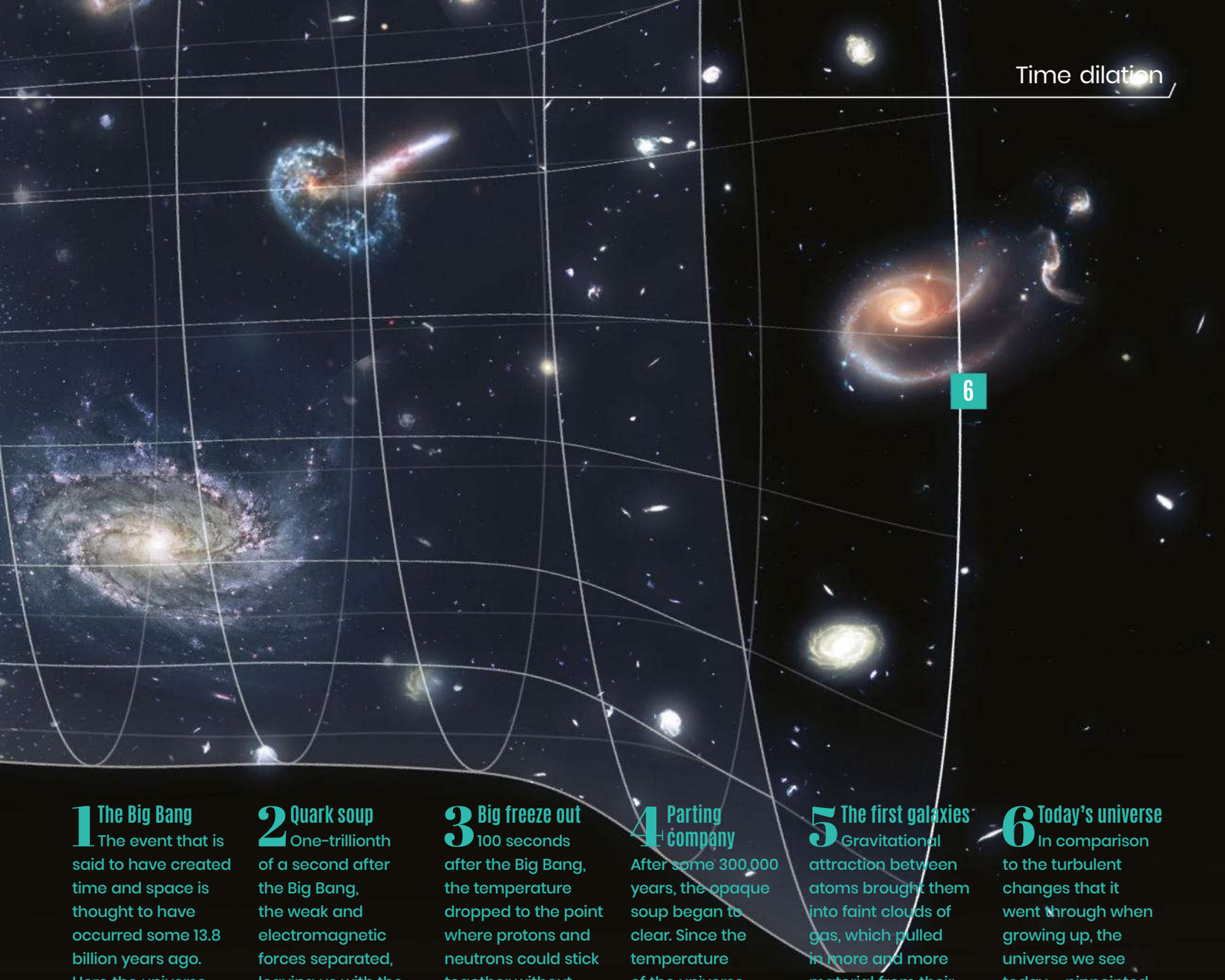
Time dilation, brought about by the relativistic expansion of space, has resulted in the observed slowing of 'clocks' in the early universe

Reported by Tariq Malik

Time has been observed passing more slowly in quasars in the early universe. The observed time dilation comes as a consequence of Einstein's theory of general relativity combined with the expansion of space. "At its heart, this is another 'Einstein is right again' story," Geraint Lewis, a cosmologist at the University of Sydney, said. Lewis and Brendon Brewer of the University of Auckland are co-authors on a new paper describing the confirmation of time dilation effects in the variability of quasars. A quasar is powered by an accreting supermassive black hole at the heart of an active galaxy. Because the accretion disc around the black hole is relatively small, fluctuations in the light emitted by the quasar can take place in just days. This makes them easier to track.

However, in the time since the light was emitted from the 12-billion-year-old quasars, the universe has expanded greatly. This means that we are seeing the quasars as they existed over 12 billion years ago. "We expected quasars to also exhibit this behaviour, but previous searches had failed to find it," said Lewis. A new sample of 190 high-redshift quasars observed over 20 years by the Sloan Digital Sky Survey (SDSS), Pan-STARRS and the Dark Energy Survey has provided us with the tools to finally detect time dilation in the variability of quasar light. The long period of observation, coupled with telescopic sensitivity to the quasar fluctuations, reveals the time dilation effect. Based on how slowly the fluctuations seem to be occurring, time in these quasars appears to run five times slower than it does for us in our frame of reference on Earth.

Time didn't really run slow in those quasars relative to everything around them – in their frame of reference, time ran normally. Einstein's theory of relativity and how he described the passage of time is based on the concept of frames of reference, and that these frames can be distinguished by their velocity relative to each other. "The motion of distant galaxies is due to



1 The Big Bang
The event that is said to have created time and space is thought to have occurred some 13.8 billion years ago. Here the universe was infinitely hot and dense before cooling and inflating.

2 Quark soup
One-trillionth of a second after the Big Bang, the weak and electromagnetic forces separated, leaving us with the four major forces we know today: strong, weak, electromagnetic and gravity.

3 Big freeze out
100 seconds after the Big Bang, the temperature dropped to the point where protons and neutrons could stick together without being torn apart. Conditions were ripe for hydrogen to form.

4 Parting company
After some 300,000 years, the opaque soup began to clear. Since the temperature of the universe had dropped, photons were travelling through the universe, free from matter.

5 The first galaxies
Gravitational attraction between atoms brought them into faint clouds of gas, which pulled in more and more material from their surroundings. Around 1 billion years after the Big Bang, the first stars and galaxies were born.

6 Today's universe
In comparison to the turbulent changes that it went through when growing up, the universe we see today – pinpointed with galaxies, stars and planets, among other structures – is much calmer.

expanding space," said Lewis. Consider that the Hubble constant describes how fast a volume of space 3.26 million light years across is expanding per second. This is an incremental effect, where the expanding volumes of space add up. The farther a galaxy is from us, the more space has expanded between the galaxy and us and the faster that galaxy seems to be moving away from us. "Some of these quasars were moving faster than the speed of light, relative to us, when the photons were emitted," said Lewis.

As Einstein showed, strange things happen when you approach the speed of light. One of these is time dilation. A stationary observer on Earth would observe a clock travelling faster than them, whether on a spacecraft or in a quasar, appear to slow down. The faster the clock is moving, the greater the effect. At velocities approaching the speed of light, the effect is dramatically pronounced, resulting in peculiarities such as the twin paradox.

Time dilation isn't theoretical. It's been observed in tiny amounts in satellites orbiting Earth. Time dilation has been observed in supernovae that exploded 6 to 7 billion years ago, but never in objects more distant than that until now. Besides being another successful test of Einstein's theory of relativity, the time dilation observed in the quasars is also further evidence that we do indeed live in a universe that is expanding as a result of the Big Bang.

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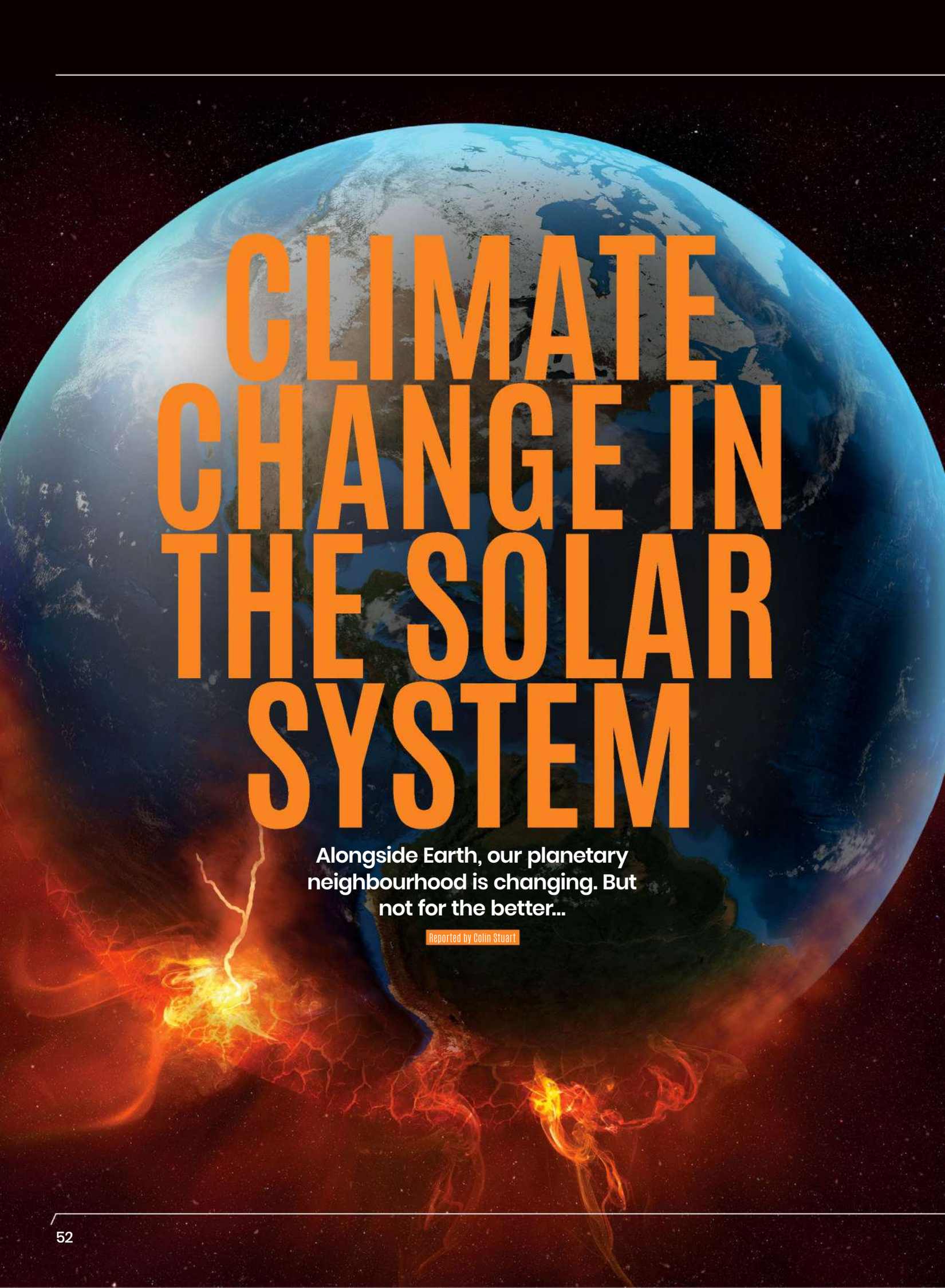


CLIMATE CHANGE IN THE SOLAR SYSTEM

Alongside Earth, our planetary neighbourhood is changing. But not for the better...

Reported by Colin Stuart

It's no secret that Earth is in trouble, and it's largely our fault. Since the Industrial Revolution we have been pumping so much carbon dioxide and other greenhouse gases into the atmosphere that our planet is rapidly warming. The race is on to keep the rise to under 1.5 degrees Celsius (2.7 degrees Fahrenheit), but it's a target we're predicted to miss. The consequences could be dire: rising sea levels, water shortages, increased migration and the possibility of more frequent wars as we battle each other for resources.

Climate change could turn out to be the greatest foe we've ever faced, and it's largely of our own making, yet there's still time to turn things around. Public awareness of the issue has never been higher, and governments and individuals alike are slowly starting to wake up to their responsibilities – but will it all be too late? Part of the trouble is that the climate of a planet is an incredibly complex system with a lot of moving parts. Throughout its history, Earth has warmed and cooled all on its own, alternating between ice ages and more temperate phases. How do we tease out our contributions from these background ups and downs? According to Dr Nicholas Attree, a research fellow at the University of Stirling, we could do a lot worse than to look at our neighbours. "What we see on Earth is natural climate cycles, plus human influence," he says. "Looking at the cycles of other planets means we can better understand our cycles and better understand our influence."

Attree has been looking closely at Mars' past climate. It's the most explored planet in the Solar System after Earth, with a host of active rovers trawling the surface and satellites whizzing around it examining the ground from on high. We've discovered that, like Earth, Mars cycles through periods with different climatic conditions. The reason is simple: gravity. Unlike Earth, Mars has no large Moon for stability. Combine that with the fact that it's closer to the Solar System's big bodies – Jupiter and Saturn – and gets bullied by its giant neighbours. Being pulled this way and that leads to a change in Mars' obliquity – the tilt of the axis on which it rotates. It also changes the shape of Mars' orbit over time, making it successively more and less circular.

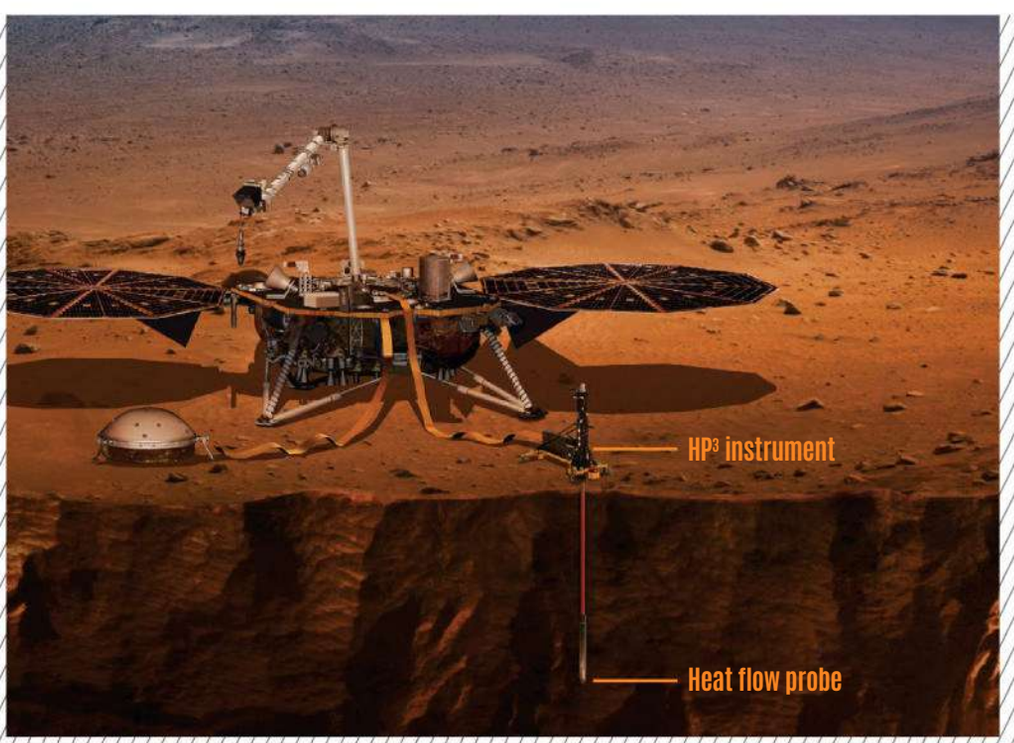
The upshot is that the intensity of sunlight falling on Mars is constantly changing, but in a regular way. A single cycle lasts tens of thousands of years. Attree has been looking at whether these climatic mood swings could have left a detectable signature on Mars today. "During warmer periods there

Cycle of ice ages

Earth's tilt changes over time, leading to changing levels of solar energy hitting the planet. Ice coverage increases and the bright ice reflects more sunlight back into space.

7 The thick clouds on Venus prevent us seeing the surface in visible light

V The HP³ probe on NASA's InSight measured Mars' internal heat



VENUS BY NUMBERS

464°C
Average temperature – about twice as hot as an oven

92
Atmospheric pressure compared to Earth – the same as being one kilometre (0.62 miles) underwater

0.69
Venus' albedo – it reflects 69 per cent of sunlight

96.5%
of the Venusian atmosphere is carbon dioxide

243
Days taken for Venus to rotate, leading to a static climate

60
Winds move 60 times faster than Venus spins

600 million years
Venus' age when runaway greenhouse effects began

© Getty / NASA

would be an increased heat flow under the Martian surface," he says. "We've modelled how that heat would build up over time." He predicted that NASA's InSight might have been able to detect that excess heat. InSight performed science on the Red Planet between November 2018 and December 2022 and was equipped with a self-hammering 'mole' designed to burrow into the Martian dirt. Among its instruments was a thermometer – the Heat Flow and Physical Properties Package, or HP^3, for looking at Mars' subsurface heat.

Unfortunately, the mission was beset with difficulties. On its first attempt the mole reached a depth of just 35 centimetres (13.8 inches) before getting stuck. With the buildup of Martian dust on the InSight lander's solar panels taking it out of commission in 2022, detecting Attree's predicted excess with the craft now looks difficult. "We were only likely to find it if the instrument functioned perfectly," he says. All is not lost, however.

There's another way to keep track of Mars' past climate cycles: carbon dioxide. Today the gas that's causing us so many woes on Earth is the main constituent of the Martian atmosphere. Yet the air is so thin that the atmospheric pressure on Mars is just 0.6 per cent of Earth's. Carbon dioxide is also frozen into the Martian ice caps. When changes to Mars' orbit and tilt increase the Sun's intensity, the carbon dioxide ice sublimates – turns straight from a solid to a gas – and more carbon dioxide is added to the Martian atmosphere. When things turn colder, the gas is deposited back onto the ice caps.

In the 1960s it was predicted that the atmospheric pressure on Mars cycles in this way, getting as low as four times less than today's level and as high as double. Yet evidence to back this up has remained elusive. Then, in December 2019, a new study claimed to have found it at long last.

It all hinges on the layers of carbon dioxide dry ice and water ice on the planet's south pole. A kilometre (0.62 miles) deep, it contains as much carbon dioxide as currently exists in the entire atmosphere. Radar measurements from orbiting satellites suggest the cap is formed of alternating layers of dry and water ice. Dry ice trapped under water ice shouldn't be stable, yet it seems to persist.

Modelling by Peter Buhler, a research scientist at the Planetary Science Institute, is attempting to explain its longevity. Each time Mars warms up, some of the dry ice remains trapped under the water ice. The carbon dioxide that does escape is eventually deposited back on top of the water ice when temperatures plummet. That leads to the layering we see. Studying

Some researchers argue that Venus would have been a potentially habitable planet long ago

THE CHANGING CLIMATE OF VENUS

According to research, our neighbour's environment has changed dramatically

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Magma ocean Early Venus was still largely molten as a result of the high-energy impacts that formed the planet in the first place. This led to a widespread ocean of magma across the planet, leading to very high temperatures.	**Gas and steam** Impacts added material to Venus, including water. An early atmosphere began to form around the planet, largely made of carbon dioxide and steam.	**Cooling and condensing** As the number of impacts began to die down, the planet began to cool and a solid crust formed on the surface. Steam started to condense out of the atmosphere and fall as rain, creating lakes, rivers and seas.	**Vociferous volcanism** Under the crust, the magma ocean persisted, leading to volcanism. We can still see these volcanoes on Venus today. Eruptions added huge quantities of carbon dioxide back into the atmosphere.	**Global warming** Carbon dioxide is a powerful greenhouse gas. It lets solar energy in, but makes it hard for it to escape. Over time this has raised the temperature on Venus, far beyond the boiling point of water. No lakes, rivers or seas remain.

these layers should allow researchers to more accurately construct a picture of Mars' climate stretching back billions of years – to a time when the planet may have been habitable. Ultimately, we may get a better answer to the question of whether there's ever been life on Mars.

According to Michael Way from NASA's Goddard Institute for Space Studies, it could also help work out where to land when planning future human missions to the Red Planet. "They'd definitely want to talk to the climate modellers," he says. "It could tell you where to place your settlements or where the subsurface water is most likely to be." Way and his colleagues have been adapting NASA's model of Earth's climate and applying it to other bodies in the Solar System, including Mars. It's known as a general circulation model. "It combines factors such as ocean circulation, wind circulation, cloud dynamics and different types of cloud," Way says. "It also estimates how many photons of light enter our atmosphere and are absorbed or reflected." Porting this model over to other worlds is not an easy task. "Applying it to modern Mars is very challenging," he says. It should get easier with the passage of time as improvements in computing power allow more intricate models to run in a shorter amount of time.

If Mars is hard, then modelling Venus' climate is even tougher. The world called Earth's 'twin' is an unforgiving hellhole. Thick clouds of carbon dioxide trap the Sun's heat, sending temperatures soaring beyond 400 degrees Celsius (752 degrees Fahrenheit). The atmospheric pressure is nearly one hundred times greater than Earth's and over 15,000 times higher than on Mars. That has severely restricted our ability to land space missions on Venus. Those that did make it to the surface succumbed very quickly to the mayhem. "We have very few data points for Venus," says Way. Unlike Mars, you can't just run rovers around, taking lots of temperature measurements. "Our models struggle as a result," he says.

The models that have been devised so far point to two different possible climatic histories for Venus, depending on how long the planet's early magma ocean hung around. The rocky planets were formed when lumps of rock and metal called planetesimals smashed into one another with such ferocity that the solid materials melted. Being closer to the Sun, whose light was more intense at the time, combined with the presence of a hot magma ocean, created an atmosphere of steam and carbon dioxide. "The atmospheric pressure would have been one thousand times greater than the modern Earth," says Way. A molecule of water is H_2O – two atoms of hydrogen bonded to one atom of oxygen. On a hot Venus this bond would have been broken regularly. The hydrogen is lost to space and the oxygen becomes trapped inside the magma ocean. "If that's the case then Venus has been a dry, desiccated world for most of the last 4 billion years," says Way. The alternative is that the magma ocean was a much shorter lived phase. "Then it would have been cool enough to condense water into lakes, rivers and oceans," says Way. In other words, far more Earth-like than today. Perhaps the Solar System had two habitable planets at the same time.

If it's the latter then Venus has experienced a huge change in climate over the last 4 billion years, largely thanks to the role of carbon dioxide. Given our current climate predicament on Earth, is there anything we

What killed the dinosaurs?

It's attributed to an asteroid, which threw huge volumes of debris into the sky and blocked out the Sun. A rapid climate change followed, which put pressure on Earth's inhabitants.

One day it may be possible to engineer Mars' climate to be more hospitable

The Huygens probe touched down on Saturn's largest moon Titan in 2005

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CLIMATE CHANGE THROUGHOUT THE SOLAR SYSTEM

5,000°C
4,000°C
3,000°C
2,000°C
1,000°C
400°C
300°C
200°C
100°C
0°C
-100°C
-200°C
-300°C
-400°C

Mercury
167°C/332°F

There's evidence of pockets of water ice at Mercury's poles, especially at points that don't see sunlight, but these would soon evaporate.

Venus
464°C/867°F

Venus is already hellish, with a thick atmosphere that consists almost entirely of carbon dioxide. That would burn away if temperatures rose further.

Earth
15°C/59°F

The effects of climate change on Earth are already well-documented. Expect rising sea levels, a loss of sea ice, heat waves that are more intense and the altering of the seasons.

Moon
-20°C/-4°F

The Moon's temperature rose by several degrees after astronauts paid it a visit – a change that wouldn't have much of an effect. Too much heat will break up the Moon's surface material.

Phobos
-4°C/25°F

Mars
-65°C/-85°F

The Red Planet has already seen climate change: a thinning atmosphere meant liquid water could no longer be stabilised on the surface. Under-surface water will eventually dry out.

Deimos
-40°C/-40°F

DEIMOS
The smaller of Mars' two moons is slowly drifting away. It will eventually escape the Red Planet's gravity and find itself on a journey into space.

PHOBOS
Phobos is less likely to be affected by climate change and more likely to find it comes to a sticky end by smashing into Mars.

GANYMEDE
There's no atmosphere to trap heat on Ganymede, but it has its own magnetic field thanks to past heating that melted ice and caused rock to sink inwards.

EUROPA
The surface temperature of Europa is largely determined by its ability to retain the Sun's heat. Ice on its surface would be lost if the moon was heated.

We know that our Sun will become a red giant in approximately 5 billion years. By then it will have consumed the terrestrial planets, though some planetary material will assimilate with this gas giant.

TITAN
As its atmosphere has warmed in the past, pockets of liquid nitrogen may have exploded from the moon's crust. It suggests Titan – which sees liquid methane fill those craters – may be susceptible to climate change.

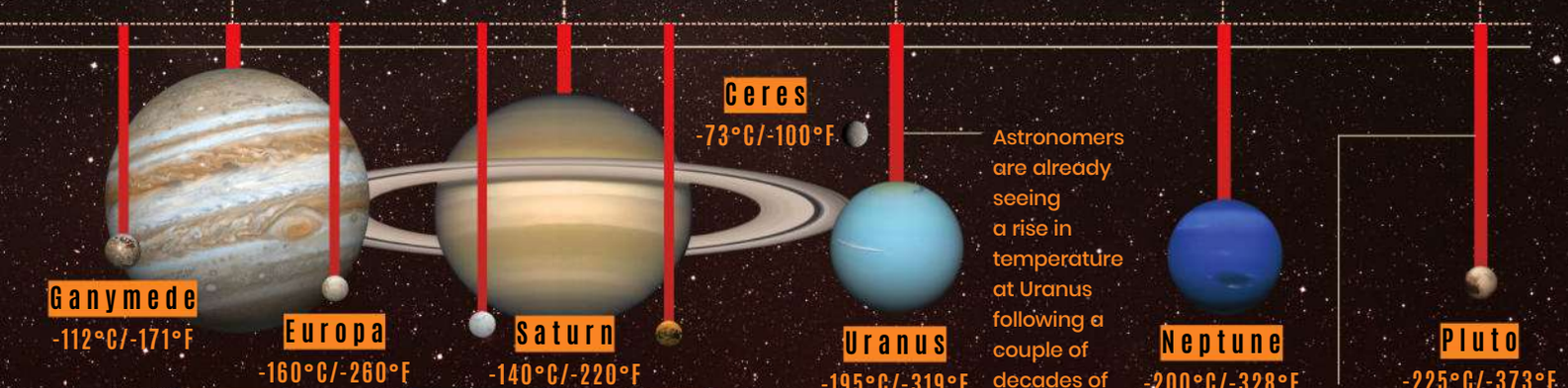
ENCELADUS
Since it's mainly covered by fresh, clean ice, Enceladus will undoubtedly suffer should temperatures rise.

In the case of the Sun becoming larger and warmer, the rings of Saturn would end up being vaporised since they are made almost entirely of water ice.

CERES
The dwarf planet Ceres is already talked of as potentially supporting life, and it is relatively warm and wet. Internal heat prevents it freezing up.

Impact of industry
We've added carbon dioxide to the atmosphere, trapping more heat from the Sun. Our planet will adjust over time, but not soon enough to avoid severely impacting our way of life.

It's odd, but Neptune, despite being further away than Uranus, is actually warmer. It's atmosphere will boil off into space as it gets hotter.



Ganymede
-112°C/-171°F

Jupiter
-110°C/-166°F

Europa
-160°C/-260°F

Enceladus
-174°C/-281°F

Saturn
-140°C/-220°F

Titan
-179°C/-290°F

Ceres
-73°C/-100°F

Uranus
-195°C/-319°F

Astronomers are already seeing a rise in temperature at Uranus following a couple of decades of cooling. It gains most of its heat from internal release.

Neptune
-200°C/-328°F

Pluto
-225°C/-373°F

When Earth is burned to a crisp, Pluto will end up being in the odd situation of having average temperatures that mirror our own today. It will have a liquid-water surface and a thick atmosphere.

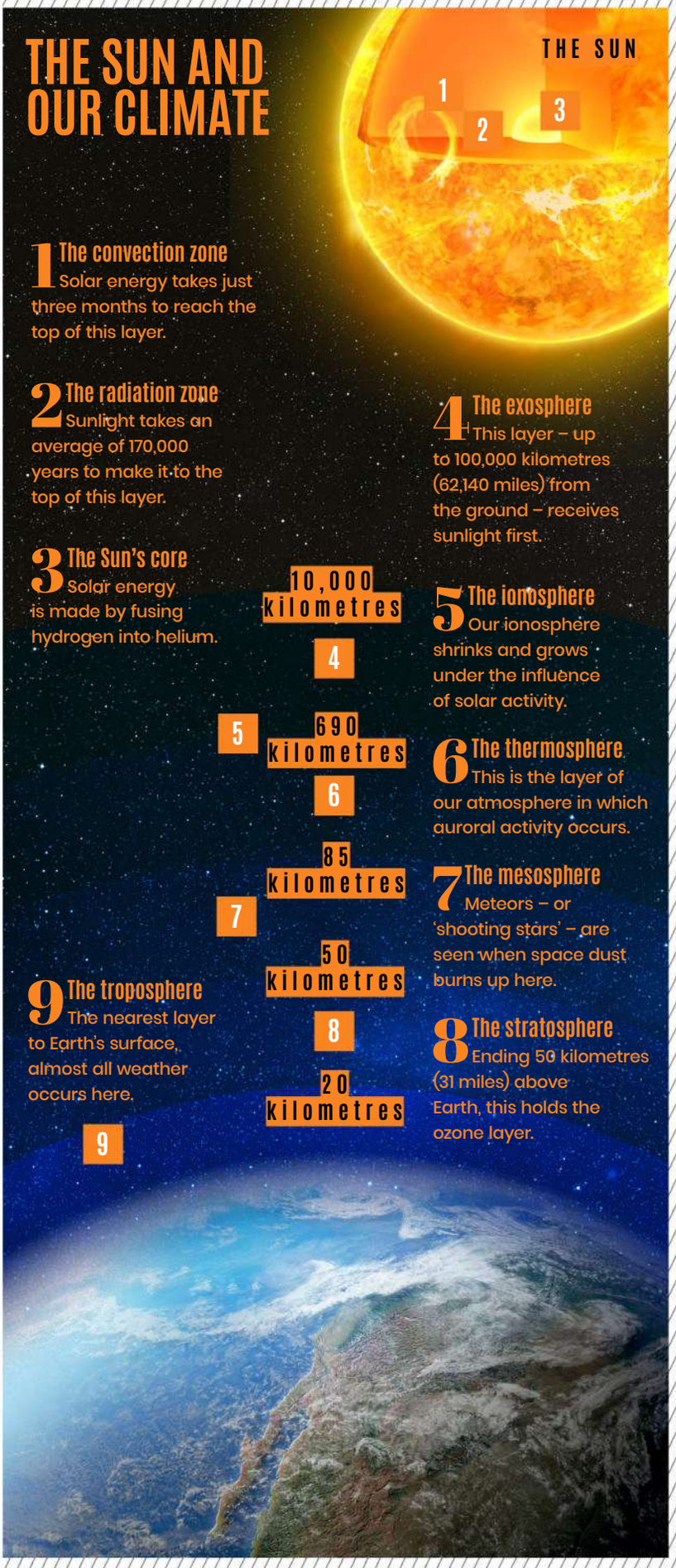
© Getty

can learn from our neighbour? "It's a compelling idea," says Way, "but it's a difficult comparison to make." The driver of Venusian climate change is largely thought to have been large-scale volcanism dumping huge quantities of carbon dioxide into the atmosphere, far more than we've added to Earth's. "Unlike Venus, Earth will eventually adjust to this increase in carbon. We just may not be around to see it," Way says.

Along with Venus and Mars, Way and his colleagues have also secured funding to model the climate of Titan – Saturn's largest satellite and the only moon in the Solar System with a thick atmosphere. "Titan is interesting as the density of its atmosphere is only 1.5 times Earth's," Way says. "A lot of its climate dynamics are similar too." Part of the attraction of studying Titan is the wealth of data that came back from the Cassini mission and the Huygens lander that touched down on the Saturnian moon in 2005. "What it found shocked a lot of us – it blew people's minds," says Way. Like Earth, there's liquid on the surface, which evaporates and condenses as rain. Yet instead of water, it's methane, possibly because of the moon's very cold temperature. Researchers have also spotted complex chemicals known to be the building blocks of life. Understanding Titan's climate today could tell us whether it has ever had suitable conditions in the past for this chemistry to jump from prebiotic chains of molecules to full-blown biological organisms. Dragonfly could be a potential game changer in this effort. In the summer of 2019, NASA announced that it had approved the audacious rotorcraft lander that would take off and land in several sites across the Saturnian satellite, much like its insect namesake. It's due for launch in 2027 and will arrive in 2034. According to Way, climate modellers are "eagerly awaiting its arrival".

All of these efforts to understand the climates of the worlds we share the Solar System with will do more than just inform our own battle against climate change. They will also give us a better idea of what exactly makes a planet habitable in the long term. That's sorely needed in the search for life beyond the Solar System. If Venus was a pleasant planet before volcanism ran rampant, then perhaps we shouldn't rule out planets in similar positions to Venus around other stars. Maybe there's too much focus on the idea of a habitable zone – the narrow region around a star where the temperature is right for liquid water. The contents of a planet's atmosphere have a huge role to play in distributing heat, and surely need to be taken into account when assessing a world's suitability for life. Who knows, one day we may have to evacuate this planet. If so, knowing which worlds around the Sun and beyond could be new potential homes could prove vital to the continuation of our species.

Colin Stuart
Astronomer and space science writer
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.



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SIX OF THE BEST SPACE PRANKS

It turns out that the sky isn't the limit when it comes to a good old-fashioned practical joke

Written by Daisy Dobrijevic

"Hopefully we brought you guys some smiles and not a lot of nervousness"

Timothy Creamer

UNAUTHORISED SPACEWALK

If you're going to pull off a prank in space, do it in style, while wearing a pair of cool shades. In 2010, NASA astronaut Timothy Creamer, Japanese astronaut Sôichi Noguchi and Russian cosmonaut Oleg Kotov beamed a snapshot of themselves floating in space back to Mission Control for an April Fool's Day prank. "You have a real problem, but you know it's outside our capability to help you," astronaut Shannon Lucid radioed the station crew, laughing all the way.

The astronauts reassured Mission Control, claiming they were wearing sunscreen and eye protection and were securely tethered so as not to float away. "We wanted to welcome you guys to April, and hopefully we brought you guys some smiles and not a lot of nervousness," station astronaut Timothy Creamer of NASA told Mission Control. "You brought a lot of laughs, that's for sure," Lucid replied.

© NASA; Getty

UNEXPECTED DELIVERY

NASA astronaut Peggy Whitson pulled off an impressive prank on the International Space Station on 13 February 2017. Whitson packed herself into a cargo bag, enlisting the help of NASA's Shane Kimbrough and the European Space Agency's Thomas Pesquet to surprise their Russian crewmates, Andrei Borisenko, Sergey Ryzhikov and Oleg Novitskiy. "They were quite surprised when I popped out!" Whitson wrote in a Twitter post. Pesquet also tried to squeeze into the cargo bag, but unfortunately it didn't quite work out. "I tried... but I didn't fit!" Pesquet wrote on Twitter.

A SMUGGLED SANDWICH

One of the earliest practical jokes carried out in space involved a contraband sandwich. On 23 March 1964, during NASA's first crewed Gemini flight, Gemini 3, pilot John Young produced a smuggled corned beef sandwich from his spacesuit pocket shortly after launch.

He offered fellow astronaut and mission commander Virgil "Gus" Grissom some, but soon realised it probably wasn't the best snack for the flight. The transcript from the mission says it all. In an interview with *Life* magazine, Young explained that "Wally Schirra had a corned-beef sandwich made up at a restaurant at Cocoa Beach a couple of days before I hid it in a pocket of my spacesuit".

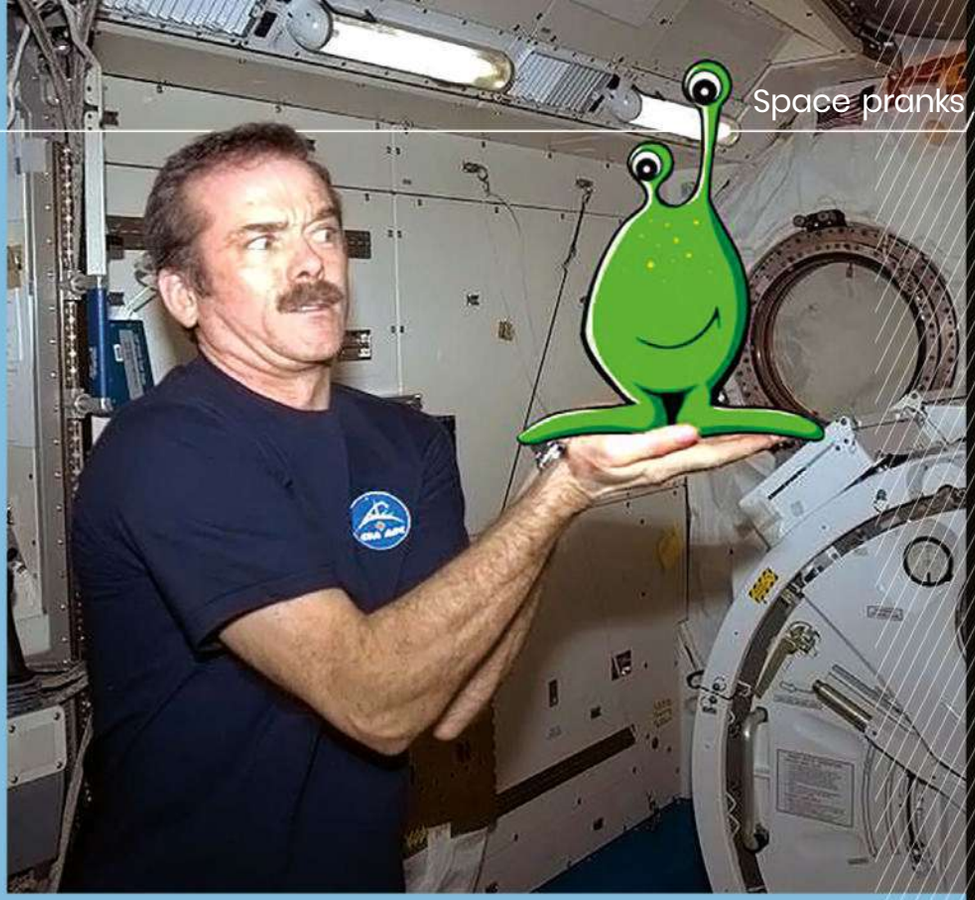
Young explained that Gus "had been bored by the official menus we'd practised in training, and it seemed like a fun idea at the time". But in reality, a several-day-old corned-beef sandwich probably wasn't the best snack to smuggle aboard. "I hadn't counted on the pungent odour in a closed cabin," Young said.

> "In reality, a several-day-old corned beef sandwich probably wasn't the best snack to smuggle aboard"

DINNER IS SERVED

In 1973, Mission Control was left rather perplexed when a female voice was transmitted from the Skylab space station, ten years before the first female astronaut, Sally Ride, made the trip into space in 1983. The voice was part of a well-planned prank that NASA astronaut Owen Garriott came up with two or three months before he embarked on the Skylab 3 mission. He made a recording of his wife Helen speaking as if she'd just arrived at Skylab for a visit, bringing the astronauts a nice home-cooked meal. Garriott had enlisted a few members of the Mission Control team to play along with the prank, including former NASA astronaut Bob Crippen. Then Garriott proceeded to transmit his wife's message down to Mission Control using their radio channel. Helen was heard saying: "I just came up to bring the boys a home-cooked meal."

According to Garriott, it took everyone who wasn't in on the prank by surprise. The team on the ground never figured out what they had done or how they had managed to pull it off. 20 years after the prank, Garriott asked some of the ground controllers who were still with NASA, "Did you know what happened?" They replied, "We never did figure that out." Eventually, Garriott came clean and told the staff how he'd pulled off the trick, 20 years after it happened. "I always thought that was an interesting gotcha," Garriot said.



JUST POPPED BY TO SAY HELLO

Canadian astronaut Chris Hadfield welcomed a rather peculiar visitor to the International Space Station on April Fool's Day in 2013. Hadfield's pranking campaign lasted seven hours, over which he slowly revealed his elaborate April Fool's Day joke on Twitter. "The view from where we fly the Canadarm2, with some orbital debris off in the distance," Hadfield wrote on Twitter. He posted a picture alongside the post showing him posing with a flying saucer-like object off in the distance.

His second photo is a little clearer, showing the UFO placed high above Earth and on its way towards the space station. "Orbital debris seems to be on a course moving a bit faster than the ISS," Hadfield wrote. "I'll try to take more pictures if it swings by." The Canadian astronaut then posted a photo of the flying saucer off in the distance with the orbiting laboratory's robotic arm in the foreground, four hours after his initial post. "Wow, what a huge piece of debris! Maybe I can grab it with the Canadarm2," Hadfield continued. Quickly after that, Hadfield wrote: "The object appears to be coming closer to the station. I think it might be trying to board us!" Hadfield then posted a photo of himself holding a small green alien away from him with both hands. "I don't know what it is or what it wants, but it keeps repeating 'Sloof Lirpa' over and over," Hadfield wrote. "Alert the press." 'Sloof Lirpa' is actually April Fools spelled backwards.

GORILLA ON THE LOOSE

Astronaut Scott Kelly is responsible for one of the most outlandish pranks in space – he dressed in a gorilla suit and chased his fellow Expedition 46 cremate Tim Peake around the International Space Station. "Needed a little humour to lighten up a #YearInSpace," Kelly wrote on Twitter on 23 February 2016. "Go big or go home. I think I'll do both. #SpaceApe." But where do you get hold of a gorilla suit while in space? Scott's twin brother, astronaut Mark Kelly, arranged for the delivery of the costume to the ISS to surprise Scott for his birthday during his year-long mission.

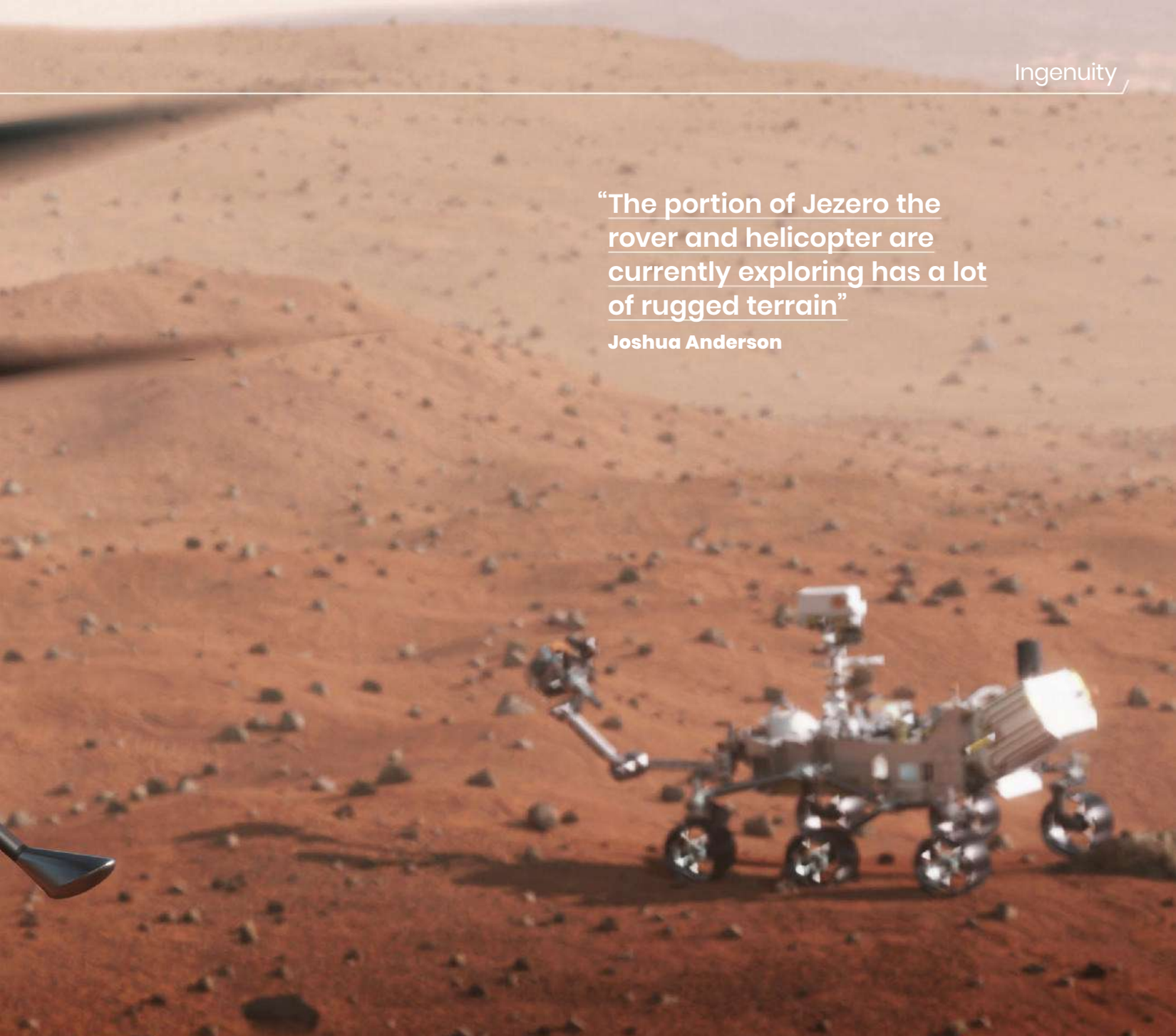
© NASA

FOCUS ON

MARS HELICOPTER PHONES HOME AFTER A 63-DAY SILENCE

Rugged terrain had kept Ingenuity from communicating with its robotic partner, the Perseverance rover

Reported by Mike Wall



> "The portion of Jezero the rover and helicopter are currently exploring has a lot of rugged terrain"
> **Joshua Anderson**

The Mars helicopter's two-month silent stretch is over. Ingenuity got in touch with its handlers on 28 June via its robotic partner, the Perseverance rover. It was the first such communication since 26 April, when the 1.8-kilogram chopper went dark towards the end of its 52nd flight on the floor of Mars' Jezero crater. "The portion of Jezero the rover and helicopter are currently exploring has a lot of rugged terrain, which makes communications dropouts more likely," Ingenuity team lead Joshua Anderson of NASA's Jet Propulsion Laboratory said. "The team's goal is to keep Ingenuity ahead of Perseverance, which occasionally involves temporarily pushing beyond communication limits," Anderson added. "We're excited to be back in communications range with Ingenuity and receive confirmation of Flight 52."

Ingenuity covered 363 metres (1,191 feet) of ground on the 139-second Flight 52. The main goals of the sortie were to reposition the chopper and snap photos for Perseverance's science team, NASA officials said.

The newly received flight data suggests that Ingenuity remains in good health. If further checkouts confirm that, the chopper could fly again within the next few weeks, team members said.

Ingenuity and the life-hunting, sample-collecting Perseverance landed inside Jezero crater in February 2021. The chopper quickly aced its primary mission, a five-flight campaign designed to show that aerial exploration is feasible on Mars. Ingenuity then embarked on an extended mission, during which it served as a scout for Perseverance.

All communications to and from Ingenuity must be routed through Perseverance. That explains the recent silent spell, which the two mission teams had expected. The rover had disappeared behind a hill from the helicopter's perspective, and it didn't come back into view until 28 June. Ingenuity's handlers have battled through other communications issues lately as well. In early April the chopper went dark for six days, a surprise dropout that had the mission team sweating a bit.

The helicopter and rover work in tandem while exploring Mars

© Getty

MYSTERIES OF THE UNIVERSE

WHY DOES JUPITER CHANGE COLOUR?

For years, scientists have tried to work out why Jupiter's bands frequently move and change colour. Now they believe they've found the answer

Reported by David Crookes

Professor Chris Jones of the University of Leeds has been fascinated by Jupiter for more than 60 years. He says that he became interested in what lies beneath the gas giant's surface when he was a child, and since then his work has included many studies into the Solar System's largest planet. He's well aware of the many mysteries surrounding Jupiter, such as how it formed, the nature of its core and how it became enriched in heavy elements compared with the Sun. Scientists have also wrestled with the mystery of Jupiter's colour-changing stripes, but this is something that Jones has gone a long way towards answering.

If you look at Jupiter, you'll see many distinguishing features, not least the bands of colour and the famous Great Red Spot – a persistent high-pressure region in the atmosphere which is twice as wide as Earth. The pale stripes are known as zones, while the darker ones are called belts. The belts are cyclonic and the zones are anticyclonic, and fast jet streams occur at their boundaries. "The colours of the features seen on Jupiter are a consequence of the rising gas brought up from the interior by convection," Jones explains. "The striped appearance arises because there are very fast east-west winds on Jupiter, so these gases rapidly spread out along lines of latitude."

In other words, the strong winds give rise to the stripes, with the effect being bands of colour that swirl around. The mystery, however, lies in why the stripes change colour, size and location every four to five years. This phenomenon has been noted ever since Italian astronomer Galileo Galilei began to observe the gas giant in the early 17th century, and became clearer when the Hubble Space Telescope caught Jupiter changing its stripes via high-resolution images in the mid-2000s. Back then, Hubble's Wide Field and Planetary Camera 2 captured entire bands of clouds changing colour, with zones darkening into belts and belts lightening and transforming into zones.

"It poses interesting questions," says Jones. "Why are the east-west winds so strong, why do they change direction from easterly to westerly as the latitude changes and why do the stripes change their appearance with time? The winds are pretty constant and their latitude location is very constant. The convection is sometimes particularly strong and brings up

© Getty

JUPITER'S STRIPES BY NUMBERS

3
Number of distinct cloud layers

2
Different stripe types: belts and zones

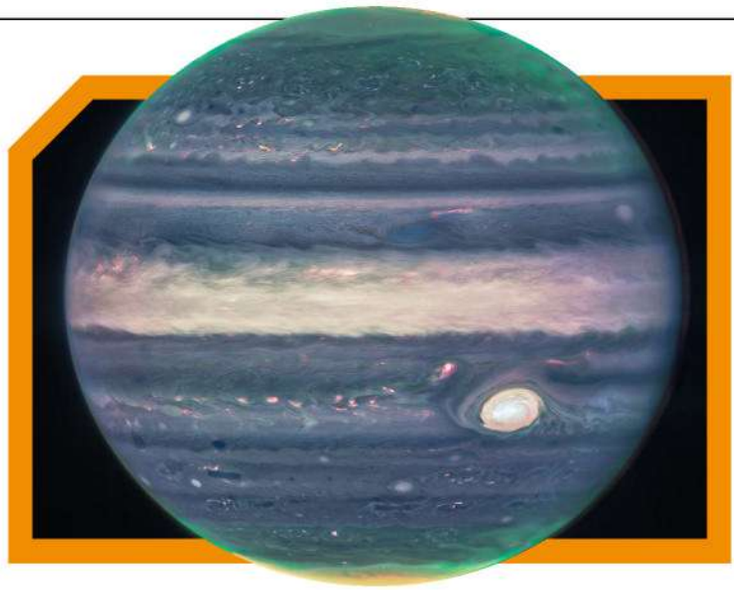
71
The span of the layers in kilometres

3,200
Depth, in kilometres, of the strong east-west winds

65
Depth, in kilometres, beneath Jupiter's water clouds where the belts and zones undergo a transition

5
The most prominent colours on Jupiter are red, orange, brown, yellow and white

2016
The year Juno arrived at Jupiter



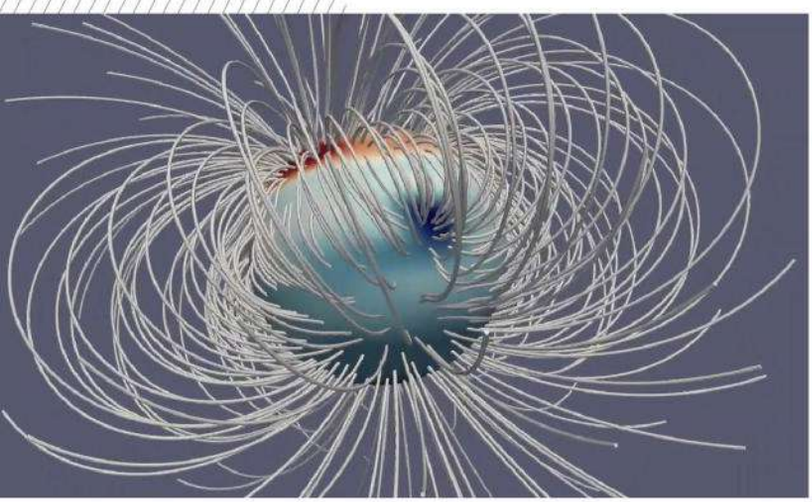
different gases from below. Sometimes it's relatively weak and the appearance doesn't change much, but the times of particularly strong convection have been called 'global upheavals' by Jupiter watchers." Quite why these happen has been the subject of a recent study by Jones. Aided by Dr Kumiko Hori from Kobe University in Japan, Professor Steven Tobias at the University of Leeds, Professor Leigh Fletcher from the University of Leicester and Dr Arrate Antuñano at Universidad del País Vasco in Spain, the work has drawn on past studies as well as data from NASA's Jupiter-orbiting Juno spacecraft.

In the process, the team has been able to link two areas of study, drawing together research probing the deep interior of the planet with studies into Jupiter's weather and what happens on the surface. They have worked with the knowledge that the bands seen on Jupiter are made up of clouds of ammonia and water in a hydrogen and helium atmosphere and that the bands – some 1,600 kilometres (1,000 miles) deep – are linked to Jupiter's infrared variations. "The infrared observations relate more to what is going on inside Jupiter, rather than what is happening in the very turbulent atmosphere," Jones explains. "Although it was known that the surface had global upheavals on a decadal timescale, the periodic nature of the disturbances wasn't clear until the infrared measurements were carefully analysed."

Before such observations were linked to the bands, scientists had believed that the moves and changes were being caused by what was happening above rather than below them. "The changes that occur on a decadal timescale have been mostly attributed to variations and winds in the upper atmosphere, similar to the quasi-biennial oscillation in Earth's atmosphere," Jones says. "The problem with this is that the variations in the stripes seem to come from below, not from above. Also, the whole pattern is affected at the same time, whereas the quasi-biennial oscillation effects are mainly at the equator only." To take the study further, the team carefully looked at the data from Juno. The spacecraft launched from Cape Canaveral in 2011, entering a polar orbit of Jupiter in 2016. Its aim has been to understand the origin and evolution of the planet, look for a solid planetary core, measure water and ammonia in the deep atmosphere, observe aurorae and, crucially for Jones' study, map Jupiter's magnetic field.

Juno's mission was only planned to be seven years long, but it's gone beyond that, with the science phase extended to 2025. By amassing such a wealth of data about Jupiter's magnetic field, the team has been able to monitor and calculate changes, correlating the variations in the gas giant's bands to changes in its magnetic field. Since there's so much information to work with, it's enabled the team to make a breakthrough. They've been able to show that the infrared variations could be caused by waves produced by the planet's magnetic field deep within Jupiter's interior. "The form of Jupiter's magnetic field has been really accurately mapped by Juno, and we now know it almost as well as we know Earth's magnetic field," Jones explains. "This enabled us to calculate the periods expected from the magnetic waves, and the periods turned out to be similar to those seen in the infrared observations." It means that the changes being observed in the planet's bands are coinciding with magnetic oscillations within it – that the swirling clouds are being influenced by Jupiter's massive magnetic field.

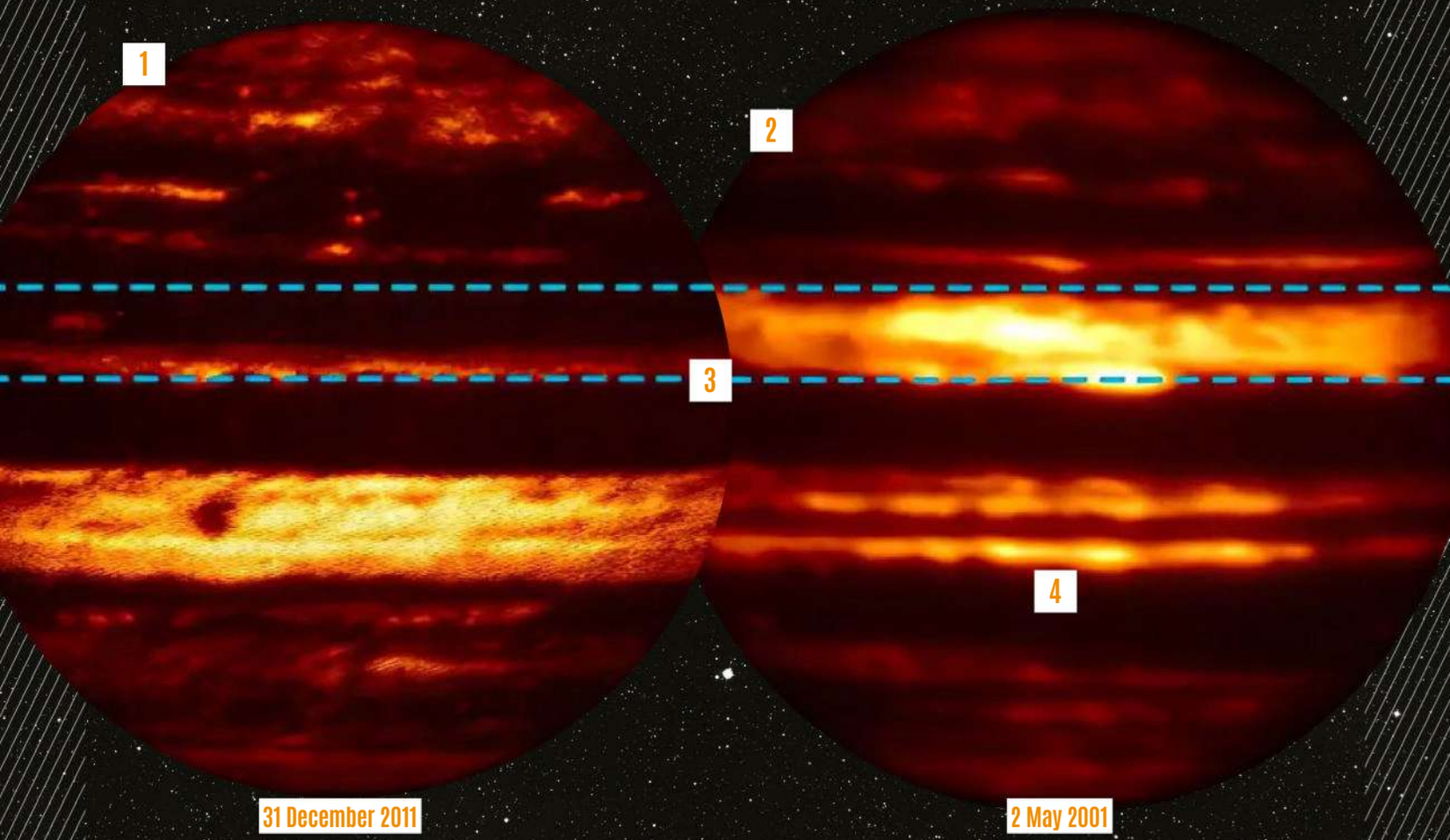
"We did find these magnetic waves in numerical simulations of Jupiter's dynamo before the Juno work, but at that stage we didn't have much information on the



The James Webb Space Telescope is sharing some of the best images of Jupiter ever seen

Juno has gathered a lot of data about Jupiter's magnetic field, which is helping scientists better understand the planet's interior structure

"The variations in the stripes seem to come from below, not from above"
Chris Jones



SPOT THE DIFFERENCE

See the exact changes that took place more than ten years apart

1 Infrared image
The image on the left was taken in December 2011 by a ground-based telescope. It shows Jupiter at five micron wavelength radiation.

2 Changing colour
The image taken just over ten years earlier in May 2001 looks remarkably different. The North Equatorial Belt appears lighter.

3 East and west
Clouds move quickly, blown by easterly and westerly winds. Close to the equator, the wind blows eastwards. It goes westward when going north or south.

4 Fast jets
Fast jets of wind occur at the boundaries between the zones and belts which make up the bands. The belts are cyclonic and the zones are anticyclonic.

© Arrate Antuñano/NASA/IRTF/NSFCam/SpeX

“The stripes on the surface vary, but they don’t show the clearly periodic behaviour seen in the infrared”

Chris Jones

© NASA

magnetic field, so we couldn't work out the periods," Jones continues. "Also, the periods seen in the infrared observations only came to light recently." It's another triumph for Juno, which has also shed more light on Jupiter's atmosphere, thin rings and Great Blue Spot. "Juno has now been in operation for seven years, so the Juno team is starting to detect changes in the magnetic field, which will enable us to see the magnetic waves directly in the magnetic field," Jones adds. "The ongoing magnetic field data from Juno should provide direct evidence of torsional waves in the near future".

But how do the waves produced by the magnetic field cause the infrared variations that lead to the changing appearance of Jupiter? "The magnetic waves are what are known as torsional waves," Jones says. "These waves give rise to a torsional oscillation in which the fluid comprising Jupiter's interior rocks backwards and forwards. This shears the convecting fluid, and we think it modulates the convective heat flux so that at some times in the cycle of the oscillation more heat gets out, and at other times less heat gets out. This behaviour is seen in lab experiments, but it's not yet well understood how it works in planetary conditions. I think this will be confirmed, but further work would be good."

The results are noticeable changes. "In the infrared, there are periodic variations in the pattern of brightness," Jones continues. "Antuñano has nice pictures of how the infrared intensity varies over time, but the periods do vary with latitude, and this is expected from our theory. The stripes on the surface also vary, but they don't show the clearly periodic behaviour seen in the infrared. We think this is because the strong turbulence near the surface messes up the signal coming from below, so what we see at the surface is a rather noisy image of what's going on deeper down."

Jones isn't finished. As Hori says: "There remain uncertainties and questions." The mystery now, he adds, is "particularly how exactly the torsional oscillation produces the observed infrared variation, which likely reflects the complex dynamics and cloud-aerosol reactions." As such, the team is very much aware that there's still more work to do, even though being able to see Jupiter's magnetic field in detail has allowed scientists to move further down the road.

"As I mentioned, the magnetic field observations can be used to directly detect the torsional oscillation, and the infrared observations can be extended," Jones says. "But on the theoretical side, much more work can be done on two issues: one is how the oscillation affects the heat transport, which at present is poorly understood. Another important issue is how possible stably stratified regions in the interior could affect the torsional oscillations. These stably stratified layers have been conjectured to exist in Jupiter, and torsional oscillations may shed more light on whether they're really there."

More work is also going to be centred on the Great Blue Spot, which is a specific intense area of magnetic field that has been moving eastwards at the planet's equator. Juno's data shows that the movement is slowing, and there's a chance, Jones explains, that it marks the start of an oscillation. There's every chance that it will reverse and move westwards, and you can bet the team will be monitoring that. "The most recent data from Juno is giving us a better insight into the Great Blue Spot, and questions such as how long it has lasted, whether it's strengthening and whether it's going to change its form are high up on the agenda. There's lots of exciting work still to do on Jupiter," says Jones.

WHAT'S THE LIKELY CAUSE OF JUPITER'S COLOUR CHANGES?

There are several theories to explain why the bands of colour alter

Strong atmospheric winds

The paler stripes, or zones, are clouds where the air is rising. The darker stripes, or belts, are clouds where the air is sinking. Scientists thought that these high-speed winds, alternating from east to west, brought material up from the core to the tops of the clouds. The colours would change depending on the temperature and composition of the bands.

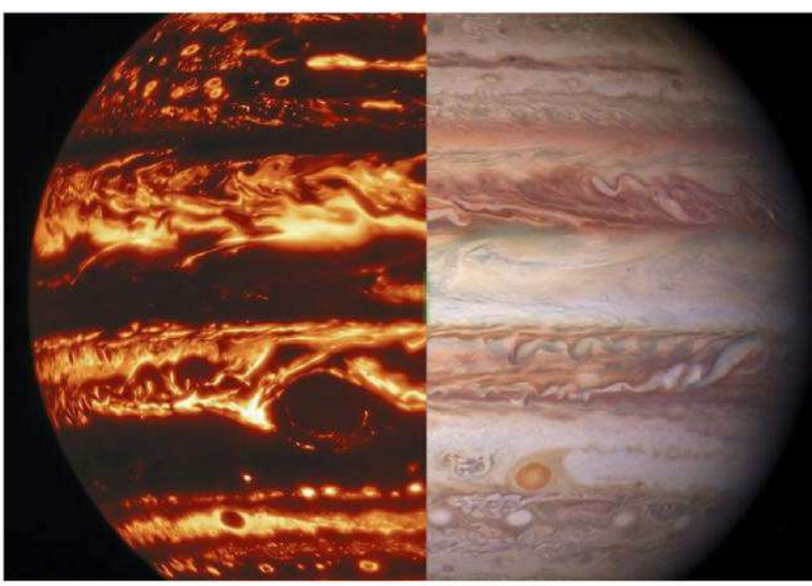
Jupiter's moons

There has also been a belief that Jupiter's moons may affect the stripes, and therefore alter their colour by acting from above to pull on the gas giant's atmospheric convection cells. But the variations in stripes appear to come from below rather than above. In that case, the moons are likely to have less of an impact than thought.

Jupiter's magnetic field

The most recent possible explanation is that shifts in Jupiter's magnetic field deep within its interior cause infrared variations and the mysterious colour changes. The wave-like motions produced by the magnetic field appear to correlate with the period of infrared variation, but more work needs to be done to establish exactly how this works.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.



This composite image shows the white cloudy zones and relatively cloud-free belts, which appear red-brown

FOCUS ON

6

A HUNGRY BLACK HOLE 'SWITCHES ON' AS ASTRONOMERS WATCH IN SURPRISE

J221951 is one of the most extreme examples yet

Reported by Robert Lea

One of the brightest transient events is the result of a supermassive black hole beginning to feast on surrounding matter, resulting in one of the most dramatic 'switching on' events ever seen. Transients are astronomical events or objects that change in brightness over short periods of time, and the one powered by this greedy black hole, J221951-484240, is one of the brightest transients ever recorded.

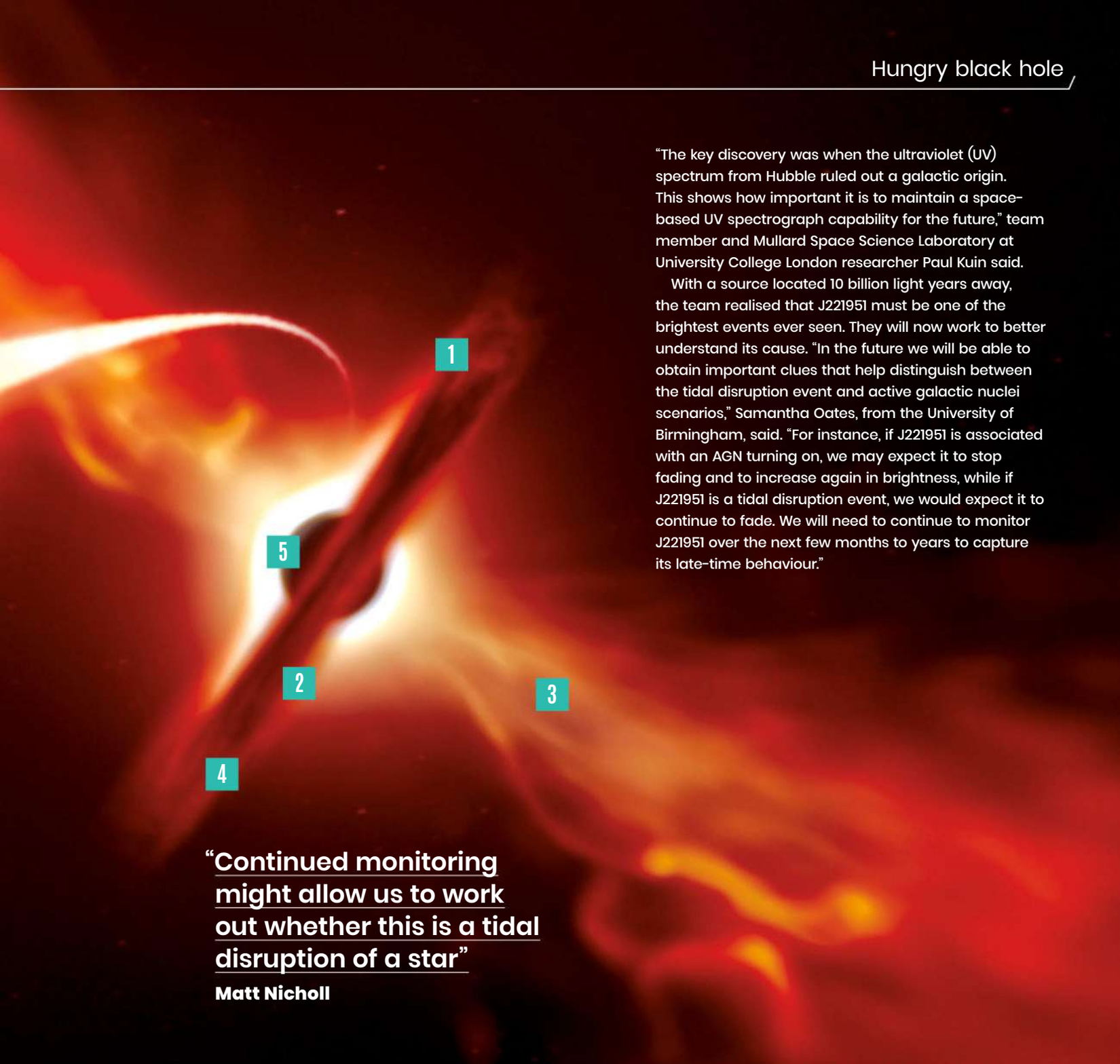
The position of the black hole corresponds with the centre of a previously observed galaxy – just where a supermassive black hole would be expected to sit. However, astronomers still aren't sure exactly what is causing the transient event witnessed in J221951. "Our understanding of the different things that supermassive black holes can do has greatly expanded in recent years, with discoveries of stars being torn apart and accreting black holes with hugely variable luminosities," Queen's University Belfast astronomer Matt Nicholl said. "J221951 is one of the most extreme examples yet of a black hole taking us by surprise."

The nature of what the supermassive black hole, located around 10 billion light years away, is consuming is currently unknown, but it's possible that J221951 represents a star that has ventured too close to the black hole being violently ripped apart by tidal forces arising from its immense gravity in a process called spaghettification. This occurrence, called a tidal disruption event (TDE), would see some of the stellar material from the destroyed star fall to the surface of the black hole while other matter is funnelled to the poles of the black hole before being blasted out at near light speeds, generating intense electromagnetic radiation.

The spaghettification of an unfortunate star isn't the only possible mechanism that could be causing the black hole in question to give rise to this bright transient event, however. Another possibility is that J221951 is the result of the nucleus at the heart of a galaxy switching from a dormant to an active state.

Active galactic nuclei (AGN) are bright areas at the hearts of galaxies that blast out enough light to drown out the combined light of every star in the rest of that galaxy. They are also powered by supermassive black holes. "Continued monitoring of J221951 to work out the total energy release might allow us to work out whether this is a tidal disruption of a star by a fast-spinning black hole or a new kind of AGN switch on," Nicholl added.

A kilonova is a type of transient event that occurs during the merger of two neutron stars, or a neutron star and a black hole, which releases bright bursts of electromagnetic radiation. Kilonovae initially have a blue coloration, then fade to red over a period of several days. The transient J221951 also appeared blue, but it didn't change to red or fade as rapidly as a kilonova would. The nature of this transient was determined by follow-ups with space-based facilities like the Hubble Space Telescope and ground-based observatories like the Very Large Telescope (VLT), located in the Atacama Desert of northern Chile.



"The key discovery was when the ultraviolet (UV) spectrum from Hubble ruled out a galactic origin. This shows how important it is to maintain a space-based UV spectrograph capability for the future," team member and Mullard Space Science Laboratory at University College London researcher Paul Kuin said.

With a source located 10 billion light years away, the team realised that J221951 must be one of the brightest events ever seen. They will now work to better understand its cause. "In the future we will be able to obtain important clues that help distinguish between the tidal disruption event and active galactic nuclei scenarios," Samantha Oates, from the University of Birmingham, said. "For instance, if J221951 is associated with an AGN turning on, we may expect it to stop fading and to increase again in brightness, while if J221951 is a tidal disruption event, we would expect it to continue to fade. We will need to continue to monitor J221951 over the next few months to years to capture its late-time behaviour."

"Continued monitoring might allow us to work out whether this is a tidal disruption of a star"

Matt Nicholl

A CLOSE-UP LOOK AT ACTIVE GALACTIC NUCLEI

1 Dust ring
A dense doughnut-like ring of dust and gas surrounds the AGN, concealing it from some angles.

2 Accretion disc
A superheated accretion disc forms as material spirals into the black hole and is torn apart by tidal forces.

3 Intergalactic jets
Far from the nucleus, jets billow into intergalactic space, producing radio emissions we can detect.

4 Radiation factory
At temperatures of millions of degrees, the accretion disc emits visible light, UV radiation and X-rays.

5 Massive black hole
Supermassive black holes can have the mass of millions of Suns and pull in everything within reach of them.

6 Polar emission
Tight particle jets emerge from the poles at close to the speed of light and produce characteristic emission lines.

© ESO

SOLAR SYSTEM

Will the Moon ever leave us?

Ocean tides driven by the Moon release energy, but that energy has to come from somewhere – the spin of Earth, which must slow down. Physics dictates that the total amount of angular momentum has to stay the same between Earth and the Moon, so the orbit of the Moon has been getting larger for billions of years. How far can the Moon get from Earth, and can it ever escape and become its own planet? If Earth was to spin down completely, the Moon would get to the distance of 87 Earth radii – now it's at 60 Earth radii. Calculations show that orbits closer than about 94 Earth radii are stable, so it looks like the Moon cannot escape, even theoretically.

To actually get to that distance the Moon may need about 15 billion years – much longer than the 5 billion years Earth has left – in which the Moon likely won't get beyond 75 Earth radii. Also, the Sun's tides steal spin from Earth, reducing what's available to the Moon. Finally, Earth's axial tilt will become chaotic in 1 to 2 billion years, misaligning the axes of Earth's spin and lunar orbit and slowing the tides further. It appears that the Moon is here to stay with Earth until its end.

Matija Ćuk, research scientist at the SETI Institute

Artist's impression of the view of Earth from the Moon

BLAPs are most likely the result of a merger of a binary star system

The Sun is predicted to reach solar maximum in 2025

STARS

What are blue large-amplitude pulsators (BLAP) and how do they differ from other pulsating stars?

Blue large-amplitude pulsators are almost half an hour pulsators, so their pulsation periods are between 20 and 40 minutes, and they have exceptionally large amplitude changes. They differ from other variable stars because of the high amplitude change in very short periods. We know the classical Cepheid, RR Lyrae and Mira stars are variable stars of much longer periods, consisting of days, weeks or even months. If you compare these BLAPs to Cepheids, Cepheids extend over a larger fraction of the star's magnitude, but their periods are much shorter. If we compare this to our Sun, a typical BLAP is about 70 per cent the diameter of the Sun. However, the change in the surface is remarkably large, because more than ten per cent, about 13 per cent, is the change in the BLAPs' diameter. If you imagine it takes only half an hour to make this change, it goes incredibly fast. What differentiates this pulsator from others is that other pulsators are mostly red giants, which are cool stars of about 3,000 to 5,000 Kelvin. These BLAPs are variable stars that are very hot. They have temperatures of about 30,000 Kelvin, making them appear blue.

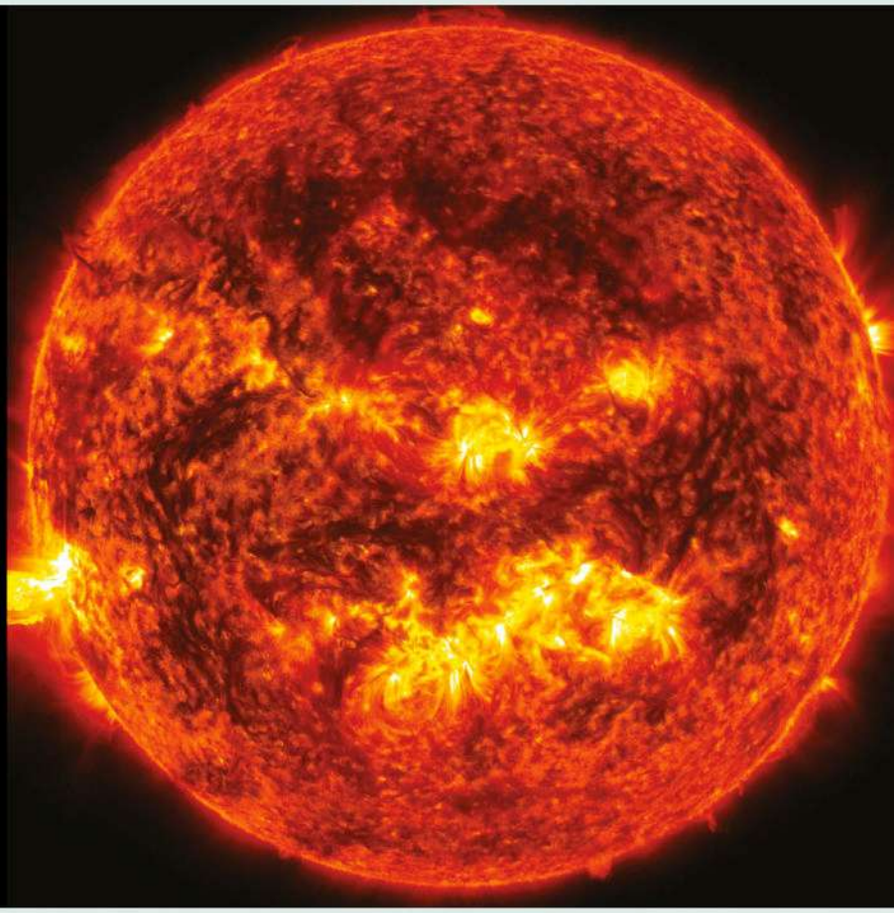
Dr Pawel Pietrukowicz, Department of Observational Astrophysics, University of Warsaw

SOLAR SYSTEM

How is space weather predicted?

The Sun and interplanetary space are monitored for notable changes in solar-related phenomena that can provide forecasters clues about the chances for space weather storms. Space weather generally refers to activity on the Sun, in the large vacuum of space between Earth and the Sun and ultimately here at and around Earth. The Space Weather Prediction Center (SWPC) is continuously staffed to monitor space weather and provide daily forecasts. Additionally, the SWPC issues warnings and alerts about substantial space weather storms and events, because they may impact technologies we rely upon today. The Sun goes through an 11-year cycle whereby solar activity is less common (solar minimum) and more frequent (solar maximum). We're now heading towards solar maximum over the next couple of years – not only will solar activity increase, but strong space weather storms will become more probable! Visit **swpc.noaa.gov** for all sorts of current space weather information and forecasts.

Shawn Dahl, space weather forecaster at the National Oceanic and Atmospheric Administration's SWPC



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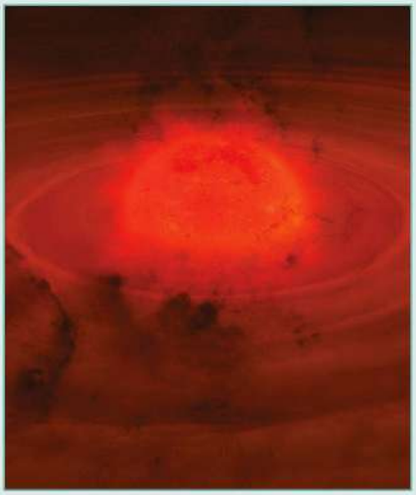


STARS

Why do discs form around protostars?

Many processes play a role in disc formation, but angular momentum is the principal quantity. The protostar and its disc are formed from the same cloud composed of gas and dust, which initially has some rotation – it has angular momentum, which is a measure of the direction and speed that something is rotating. The cloud collapses due to its own gravity, but angular momentum hinders this process – the cloud collapses into a rotating 'pancake' rather than a sphere. If the central region contains enough dense gas, then a rotating protostar will form.

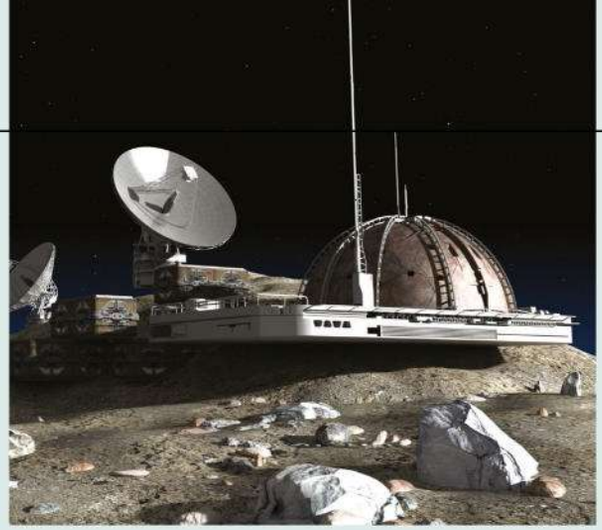
The gas and dust surrounding the new star continues to rotate. The amount of angular momentum that this gas and dust contains is one of the primary quantities that will determine its fate. If there's too little angular momentum, then the gas and dust will fall onto the star and increase its mass. However, if there's enough angular momentum then the gas and dust will remain as a rotationally supported protostellar disc. At a large enough distance from the protostar, the orbiting gas and dust will no longer be rotationally supported, indicating the outer edge of the disc. This edge is reasonably well-defined, making the disc distinct from its surroundings.

Dr James Wurster, research fellow at the University of St Andrews

© Getty / Diana Robinson Photography via Getty Images

SPACE EXPLORATION

Why can't we put a space station on the Moon?



One reason we haven't built a space station on the Moon is that we don't send people there very often. NASA is planning new missions to take astronauts to the Moon. However, there is a big difference between a short trip and building a space station on the Moon, which is extremely difficult. One way to do it would be to build it in pieces on Earth, take the pieces to the Moon and assemble them there. This would be like how the International Space Station was built: pieces were taken into space and then put together by astronauts aboard the Space Shuttle. However, the International Space Station is only 400 kilometres (250 miles) from the surface of Earth. The Moon is 384,000 kilometres (230,000 miles) away. Each trip to the Moon would take about three days and would require incredible amounts of fuel, potentially adding to climate problems on Earth.

Dr Ian Whittaker, senior lecturer in physics at Nottingham Trent University

A space station on the Moon could be very useful, but difficult to build

Planets can form from these dusty discs

Wormholes remain purely theoretical

ASTROPHYSICS

Could we ever prove that wormholes exist?

We don't know if wormholes exist, but if they do, it's likely that one day we will find them. Traversable wormholes are unlikely to exist, since there are no known physical mechanisms that can create them or keep them open. A hypothesised form of matter with antigravity effects may keep wormholes open. However, no such exotic matter has ever been observed. Despite the unlikely odds, some scientists are thinking of how to detect wormholes. Some wormholes could be black hole 'mimickers' – they have a positive effective mass, which means that they act like black holes. For example, a wormhole may bend the light from a star by passing in front of it in an effect called gravitational microlensing. Other wormholes may have an accretion disc, like supermassive black holes. The light from this disc can encode information about the space-time distortion around the wormhole, which may be different than around a black hole.

It may also become possible to image the shadow of a wormhole directly, just as was done for the black hole in Messier 87. Wormholes may stand out by having differently shaped shadows. The detection of gravitational waves from a black hole merging with a wormhole could also be within reach of next-generation gravitational observatories.

Dr Andreea Font, computational astrophysicist at Liverpool John Moores University

SEARCH FOR LIFE

What is a technosignature?

A technosignature is a signal that, if detected, would show that we earthlings are not the only form of intelligent life in the universe. More precisely, a technosignature is any measurable signal, effect or phenomenon that provides scientific evidence of past or present technology from beyond Earth. The term technosignature comes from the search for extraterrestrial intelligence (SETI). The goal of SETI is to find evidence of intelligent life beyond Earth, or to place meaningful limits on the prevalence of intelligent life. Detecting a technosignature would tell us that we are not alone in the universe and would be one of the most profound scientific discoveries ever made.

No compelling technosignatures have been found to date. But Breakthrough Listen Candidate 1 (BLC1) is an interesting signal that had many of the characteristics we expect from a technosignature. BLC1 appeared to be coming from the direction of our nearest neighbour, Proxima Centauri, and lasted for over five hours. The BLC1 signal passed all our data quality and interference filters, but after exhaustive analysis we were able to conclude that BLC1 was radio interference from here on Earth... so the search continues. While BLC1 is not a technosignature, it was a fantastic test of our pipelines and helped us create new verification tests for future technosignature candidates.

Dr Danny Price, Australian project scientist for Breakthrough Listen at the International Centre for Radio Astronomy Research

"Detecting a technosignature would tell us that we are not alone in the universe"

METEOR SHOWER VIEWING

Speeding through the atmosphere at thousands of miles per hour, meteor showers offer an exciting view for stargazers

If you enjoy gazing up at the stars on a clear night, you might have seen what looks like a point of light streaking across the sky. "Did you see that? I think I just saw a shooting star," you might have said to a fellow observer. Technically, these are not stars, but meteors, and they are often so fast and sporadic that your companion is likely to have missed your observation.

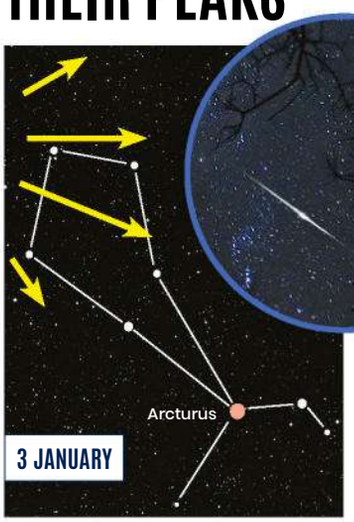
Meteors are formed when a piece of space debris called a meteoroid, micrometeoroid or space dust burns up in Earth's atmosphere. A streak of light can be seen when this happens due to the glow of the fragmenting object and the trail of burning particles that it leaves in its wake. Meteors can be seen racing across a clear sky during any time of the night and from any location. A single meteor is unpredictable, so spotting one often creates a wave of excitement. During certain times of the year, meteors can appear in huge groups, raining one after the other through our atmosphere in their hundreds in what are known as meteor showers.

These events occur roughly during the same times every year, as Earth periodically moves through the dusty trails left behind by an active or extinct comet. These showers also originate from the same point in the sky – a radiant located within or near a constellation that earns the meteor shower its name. Head out in chilly November to catch the Leonids racing from the constellation Leo, or if you prefer the warmer nights, the Perseids will offer good views in August, hailing from the constellation of Perseus.

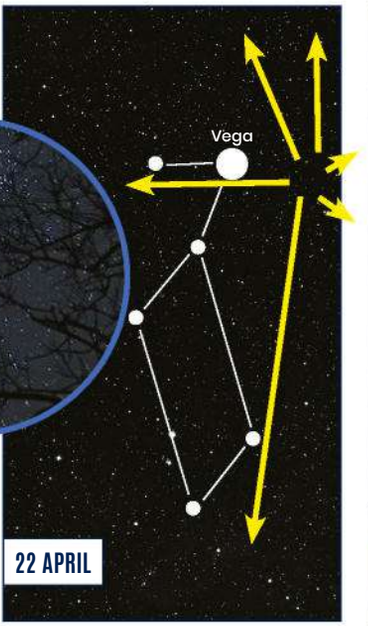
Many astronomers take great interest in recording meteor shower numbers, so you might like to report your observations – including details of their brightness, speed and colour – to official bodies such as the International Meteor Organization and International Astronomy Union. To truly get all the benefits of meteor-watching, you'll need dark-adapted vision, as well as a clear and moonless night to catch even the faintest streaks of light. However, that's not to say you won't see any meteors while the Moon is out – you're just most likely to spot the brightest of the pack. There are also the exceedingly bright meteors, often hitting magnitudes greater than those of the planets in the night sky. These are called fireballs, but if they are brighter than magnitude -14.0 they're known as bolides or superbolides.

When you picture a meteor shower, you may wrongly think of many meteors bursting out of a single point. Viewing a meteor shower requires a degree of patience, so hunting for these flashes of light turns into a waiting game. The zenithal hourly rate (ZHR) indicates the number of meteors that will appear, with some showers ranging anywhere from 5 to 100 per hour. When a shower reaches its peak, you might find the amount you see varies, but not knowing what you'll get until you begin hunting for meteors is all part of the fun.

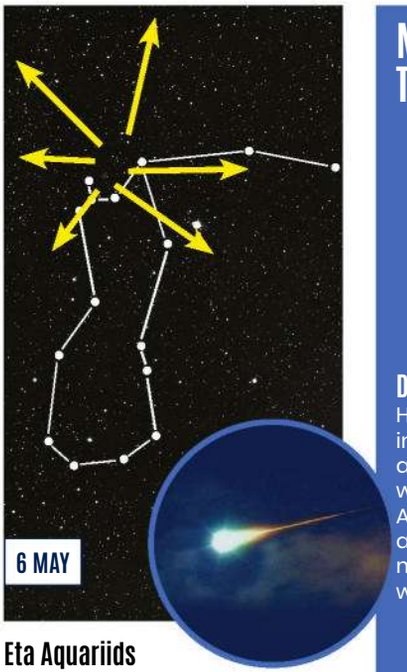
SHOWERS AND THEIR PEAKS



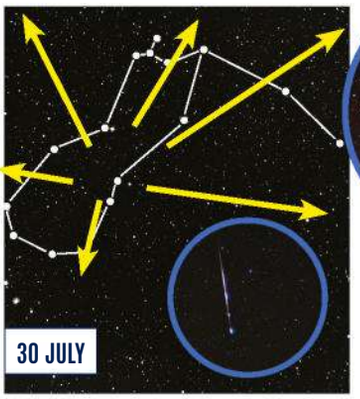
Quadrantids
Constellation: Boötes
ZHR: 120
Comet: 2003 EH1



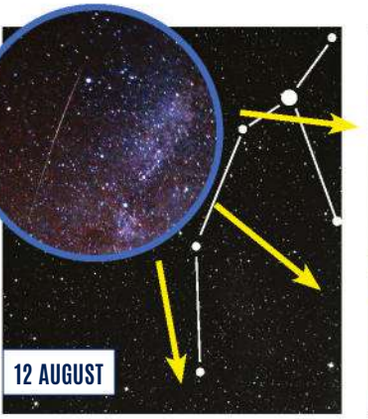
Lyrids
Constellation: Lyra
ZHR: 18
Comet: C/1861 G1



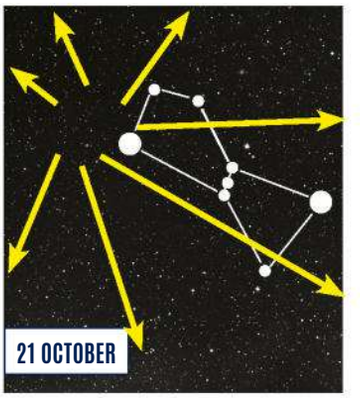
Eta Aquariids
Constellation: Aquarius
ZHR: 55
Comet: Halley



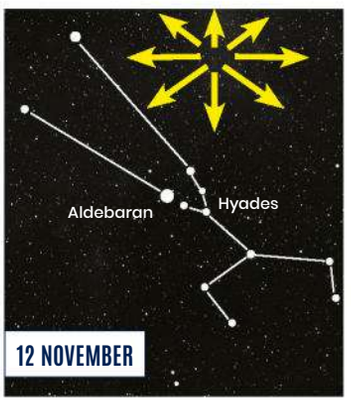
Southern Delta Aquariids
Constellation: Aquarius
ZHR: 16
Comet: 96P/Machholz



Perseids
Constellation: Perseus
ZHR: 100
Comet: Swift-Tuttle

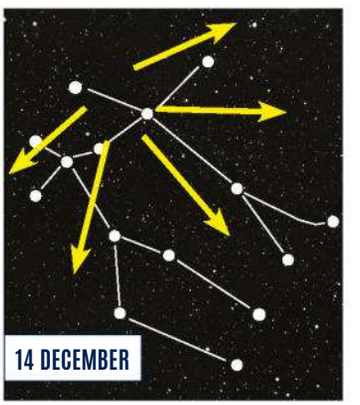


Orionids
Constellation: Orion
ZHR: 20
Parent comet: Halley



Northern Taurids
Constellation: Taurus
ZHR: 5
Comet: 2004 TG10

Leonids
Constellation: Leo
ZHR: 15
Comet: 55P/Tempel-Tuttle



Geminids
Constellation: Gemini
ZHR: 120
Comet: 3200 Phaethon

METEOR-HUNTING TOOLKIT

DECK CHAIR
Hunting for meteors will involve a considerable amount of time looking up, which can strain the neck. A deck chair will keep you at an inclined position for maximum comfort, and won't stress your neck.

WARM CLOTHING
Some showers are only observable during the winter months, so you'll need to make sure you keep warm. A hat, scarf and gloves, along with a thick coat, are essential for long periods of observing. You may also wish to use a sleeping bag.

HOT DRINK
On cold nights it's also a good idea to keep warm by drinking hot liquids. Coffee and tea are often a popular way to keep awake after midnight. If you can, have a nap before heading out.

RED FLASHLIGHT
To be able to see fainter meteors, your eyes will need to be adapted to the dark. If you're using a night-sky map or need to see in the dark, then you should use a red torch since the light will not ruin your night vision.

© Corbis; NASA/ Pierre Martin; ESA; H Hubble site

WHAT'S IN THE SKY?

What to look out for during this observing period

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88 Deep sky challenge The ghostly remains of dead stars, glittering ancient star clusters and a spectacular galaxy far, far away await

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10 AUGUST
Asteroid 10 Hygiea reaches opposition, glowing at magnitude +9.7 in Aquarius

12 AUGUST
The Perseid meteor shower reaches its peak

14 AUGUST
Globular cluster Messier 15 is well placed for observation in Pegasus

15 AUGUST
Globular cluster Messier 2 is well placed for observation in Aquarius

17 AUGUST
The Kappa Cygnid meteor shower reaches its peak

24 AUGUST
The Moon will pass in front of Delta Scorpii, creating a lunar occultation

26 AUGUST
Asteroid 8 Flora reaches opposition, glowing at magnitude +8.5 in Aquarius

27 AUGUST
Saturn reaches opposition, shining at magnitude +0.4 in Aquarius

29 AUGUST
Uranus enters retrograde motion, glowing at magnitude +5.7 in Aries

"Asteroid 8 Flora reaches opposition, glowing at magnitude +8.5 in Aquarius"

Naked eye | Naked eye warning (TAKE CARE!) | Binoculars | Small telescope | Medium telescope | Large telescope | Solar eclipse | Solstice

30 AUGUST
The Moon and Saturn pass within 2°16' of each other in Aquarius

1 SEPTEMBER
The Moon will pass in front of Uranus, creating a lunar occultation from Antarctica

1 SEPTEMBER
The Aurigid meteor shower reaches its peak

4 SEPTEMBER
Jupiter enters retrograde motion, glowing at magnitude -2.7 in Aries

4 SEPTEMBER
The Moon and Jupiter pass within 3°04' of each other in Aries

5 SEPTEMBER
The Moon and Messier 45 pass within 1°06' of each other in Taurus

9 SEPTEMBER
The September Epsilon Perseid meteor shower reaches its peak

Red-light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction
An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)
How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition
When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)
RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis we see different parts of the sky throughout the night.

Magnitude
An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of -1.0 is brighter than +2.0.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© Getty

MOON CALENDAR

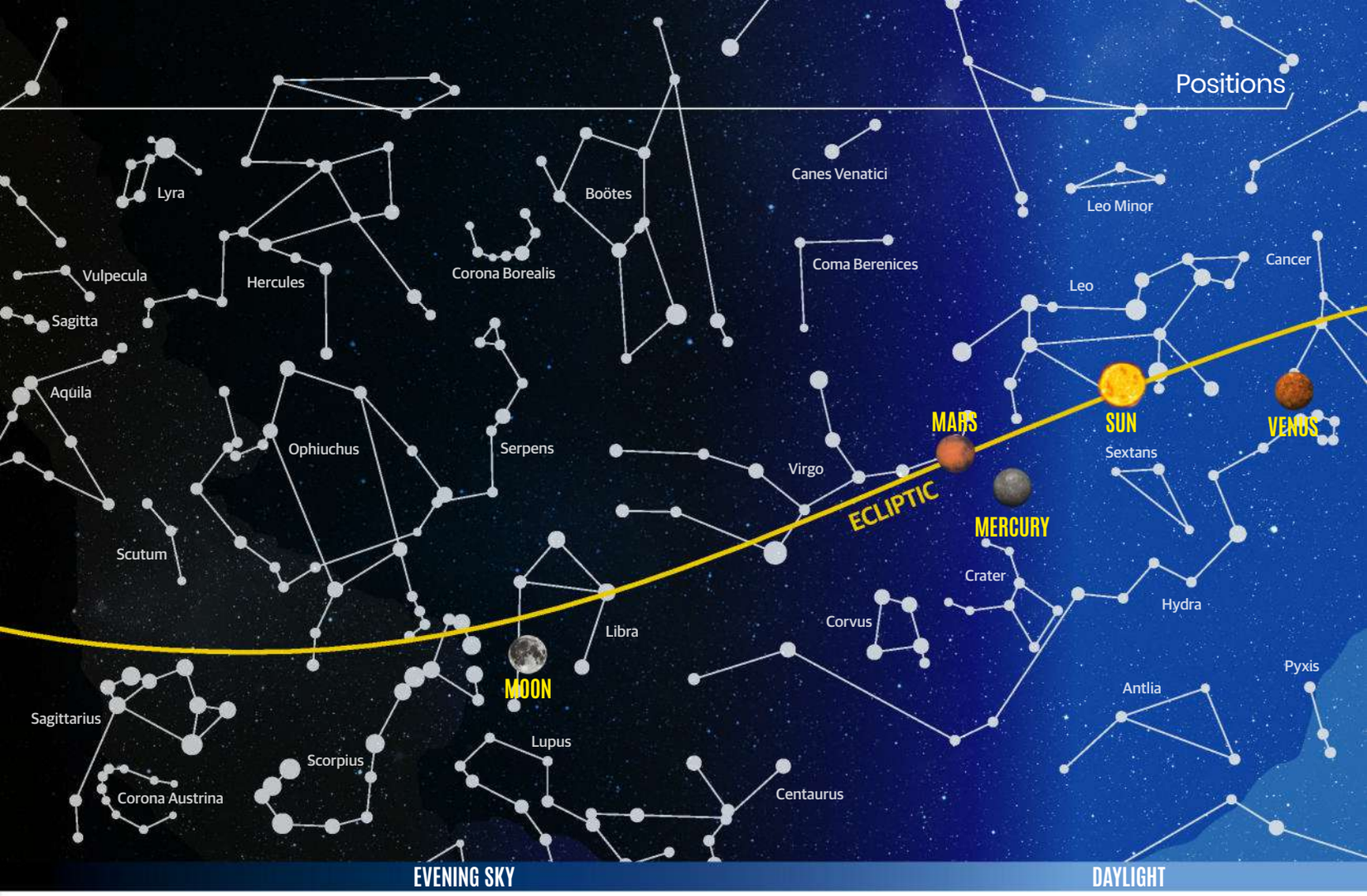
* The Moon does not pass the meridian on 29 August

10 AUG 31.3% ☾ --:-- ☽ 17:05	**11 AUG** 22.2% ☾ 00:13 ☽ 18:12	**12 AUG** 14.4% ☾ 00:55 ☽ 19:06	**13 AUG** 8.1% ☾ 01:51 ☽ 19:46			
14 AUG 3.6% ☾ 02:56 ☽ 20:16	**15 AUG** 0.9% ☾ 04:07 ☽ 20:37	**16 AUG** NM 0.2% ☾ 05:19 ☽ 20:53	**17 AUG** 1.3% ☾ 06:31 ☽ 21:06	**18 AUG** 4.3% ☾ 07:42 ☽ 21:17	**19 AUG** 9.0% ☾ 08:52 ☽ 21:27	**20 AUG** 15.5% ☾ 10:02 ☽ 21:37
21 AUG 23.4% ☾ 11:14 ☽ 21:48	**22 AUG** 32.6% ☾ 12:29 ☽ 22:02	**23 AUG** 42.8% ☾ 13:47 ☽ 22:20	**24 AUG** FQ 53.7% ☾ 15:08 ☽ 22:45	**25 AUG** 64.8% ☾ 16:29 ☽ 23:22	**26 AUG** 75.6% ☾ 17:41 ☽ --:--	**27 AUG** 85.2% ☾ 00:17 ☽ 18:38
28 AUG 92.9% ☾ 01:33 ☽ 19:19	**29 AUG** --.-%* ☾ 03:03 ☽ 19:47	**30 AUG** 98.0% ☾ 04:39 ☽ 20:07	**31 AUG** FM 99.9% ☾ 06:15 ☽ 20:23	**1 SEP** 98.5% ☾ 07:47 ☽ 20:37	**2 SEP** 94.0% ☾ 09:16 ☽ 20:50	**3 SEP** 87.0% ☾ 10:43 ☽ 21:04
4 SEP 78.1% ☾ 12:09 ☽ 21:21	**5 SEP** 68.1% ☾ 13:34 ☽ 21:43	**6 SEP** TQ 57.5% ☾ 14:54 ☽ 22:11	**7 SEP** 46.9% ☾ 16:05 ☽ 22:51			

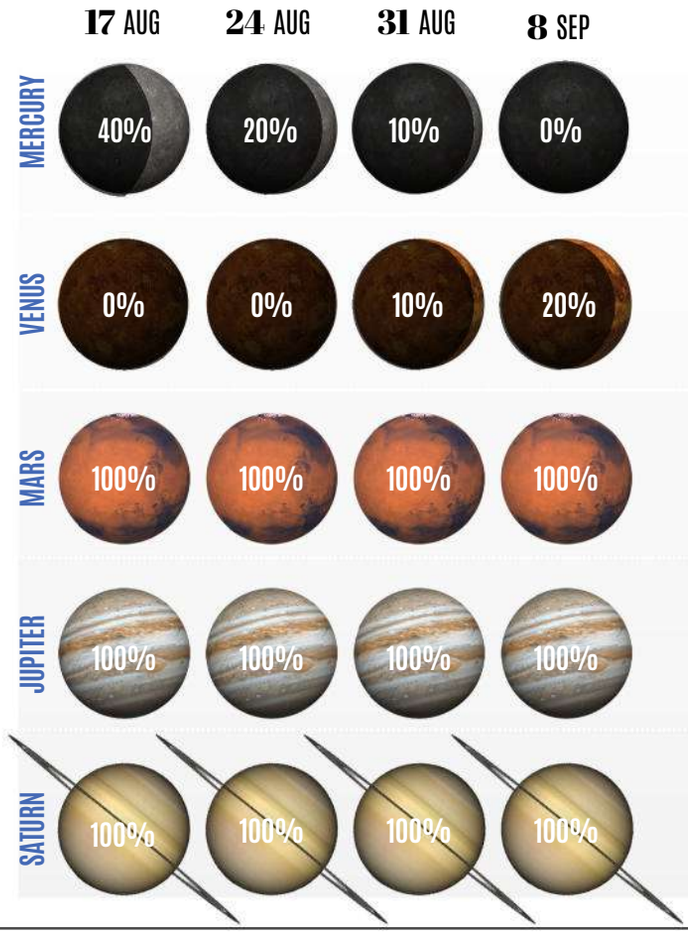
% Illumination
☾ Moonrise time
☽ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

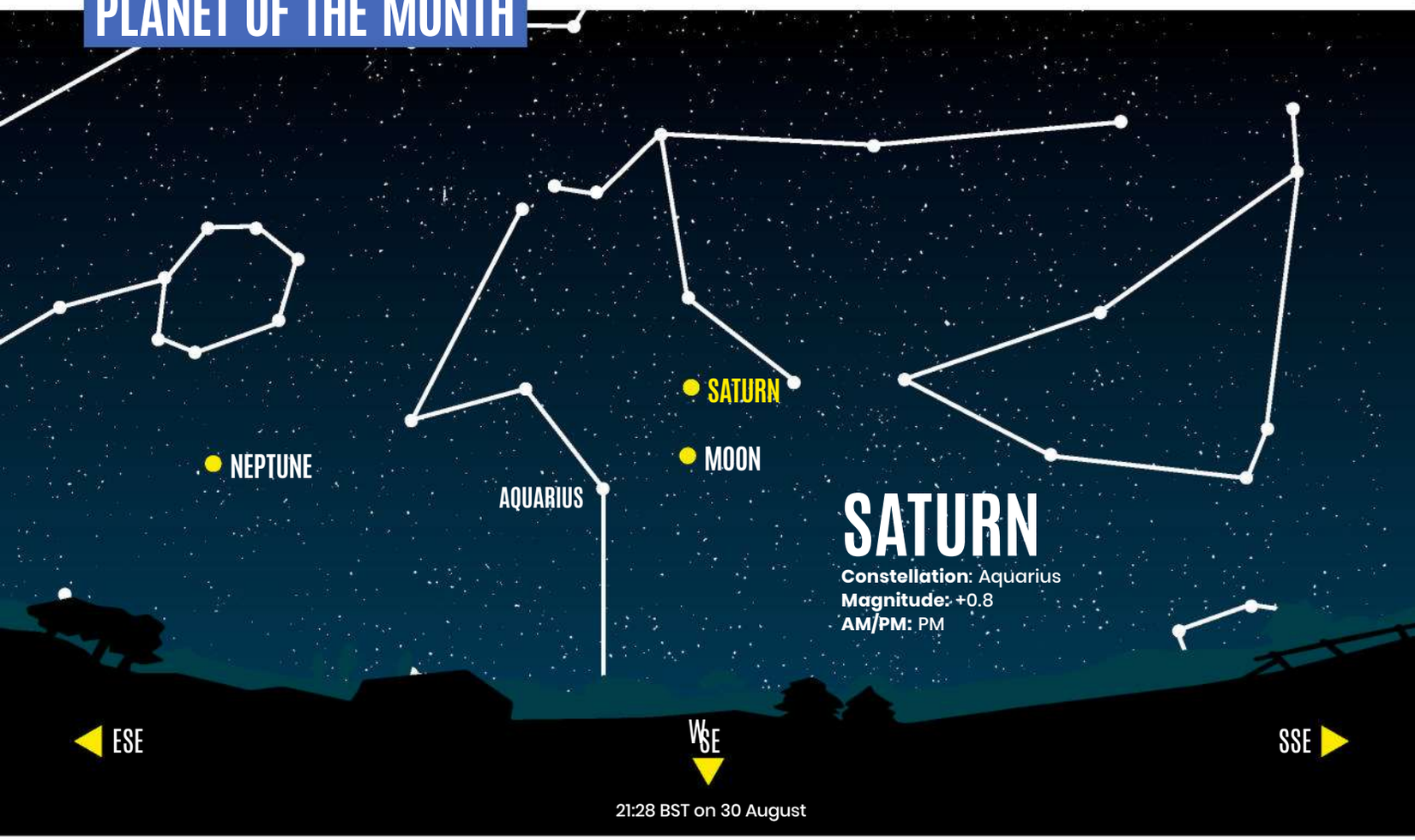
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
10 AUG	10h 59m 05s	+04° 41' 41"	Leo	+0.3	08:17	21:13
17 AUG	11h 16m 51s	+01° 25' 45"	Leo	+0.5	08:24	20:46
24 AUG	11h 22m 26s	+00° 22' 32"	Leo	+1.2	08:12	20:15
31 AUG	11h 12m 32s	+00° 11' 15"	Leo	+2.9	07:32	19:41
8 SEP	10h 47m 47s	+03° 58' 56"	Sextans	+5.1	06:16	19:04
10 AUG	09h 29m 04s	+07° 13' 47"	Leo	-4.0	06:35	19:56
17 AUG	09h 11m 48s	+07° 50' 11"	Cancer	-4.0	05:47	19:15
24 AUG	08h 57m 40s	+08° 50' 27"	Cancer	-4.2	05:00	18:38
31 AUG	08h 50m 10s	+09° 55' 21"	Cancer	-4.4	04:19	18:09
8 SEP	08h 51m 11s	+10° 55' 27"	Cancer	-4.5	03:43	17:44
10 AUG	11h 19m 08s	+05° 18' 31"	Leo	+1.8	08:34	21:36
17 AUG	11h 35m 19s	+03° 30' 44"	Leo	+1.8	08:32	21:15
24 AUG	11h 51m 34s	+01° 41' 19"	Virgo	+1.8	08:30	20:55
31 AUG	12h 07m 56s	-00° 09' 11"	Virgo	+1.8	08:28	20:34
8 SEP	12h 26m 47s	-02° 16' 10"	Virgo	+1.7	08:26	20:11
10 AUG	02h 48m 28s	+14° 54' 25"	Aries	-2.5	23:13	13:59
17 AUG	02h 50m 27s	+15° 01' 50"	Aries	-2.5	22:47	13:34
24 AUG	02h 51m 50s	+15° 06' 31"	Aries	-2.6	22:20	13:08
31 AUG	02h 52m 36s	+15° 08' 28"	Aries	-2.6	21:53	12:42
8 SEP	02h 52m 41s	+15° 07' 17"	Aries	-2.7	21:22	12:10
10 AUG	22h 29m 09s	-11° 23' 05"	Aquarius	+0.5	21:13	07:22
17 AUG	22h 27m 15s	-11° 34' 56"	Aquarius	+0.5	20:44	06:52
24 AUG	22h 25m 17s	-11° 47' 00"	Aquarius	+0.4	20:16	06:21
31 AUG	22h 23m 17s	-11° 59' 00"	Aquarius	+0.4	19:48	05:50
8 SEP	22h 21m 01s	-12° 12' 15"	Aquarius	+0.5	19:15	05:15

THIS MONTH'S PLANETS

The ringed gas giant will be gracing the evening skies for astronomers

PLANET OF THE MONTH



Even though it's quite faint and never gets very high in the sky, Saturn, the famous Ringed Planet, is still well placed for observation this month. Although it's much fainter than Venus or Jupiter, which are both also on view this month, Saturn is still lovely to look at. To your naked eye the second-largest planet in our Solar System will look like a gold-hued star, already low in the southeast as the Sun sets.

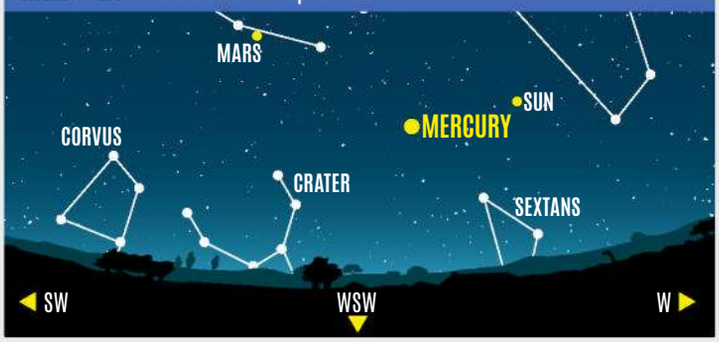
Shining at a very respectable magnitude of +0.5, Saturn will be an easy naked eye object, brighter than most of the stars in the sky. However, its low altitude means it will appear fainter than that figure suggests. The planet is currently in the zodiacal constellation of Aquarius, away from the frothy and distracting star clouds of the Milky Way, so there is good contrast between it and the sky behind it, making it easy to see through these longer and brighter summer nights.

During the month ahead you'll find Saturn shining below the 'Water Jar' of Aquarius, close to much fainter Neptune. If you're not sure where that is you'll be able to use the Moon as a guide at the very end of August. After dark on the 29th the almost-full Moon will be to the lower right of Saturn. The following evening, now full, the Moon will be shining directly beneath Saturn. And on the evening after that, the 31st, the now waning gibbous Moon will be to Saturn's lower left.

If you have a binocular handy it will really enhance Saturn's beautiful colour and show a myriad of stars glittering around it, but unless it's very large and very powerful your binocular won't show you what you probably want to see – the planet's beautiful rings. Everyone has seen photos of Saturn's magnificent icy rings in books and magazines and on space TV programs, but if you want to see them personally you're going to have to use a telescope.

Using low magnification you will be able to see the rings as a plain, cream-coloured band, or hoop, but under higher magnifications they are a magical sight. You'll see several dark gaps in the bright rings, and many of the planet's extended family of moons too. With a large telescope you'll also be able to see some features on the planet itself, such as its dark pole, cloud bands on its disc and even the ink-black shadow of the rings cast on its caramel and butterscotch-hued disc.

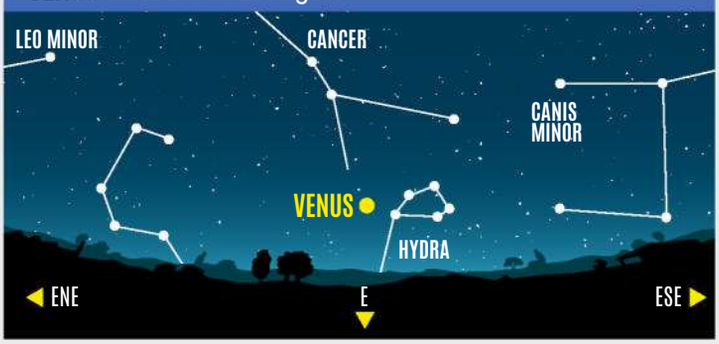
MERCURY 18:00 BST on 1 September



Constellation: Leo **Magnitude:** -1.6 **AM/PM:** PM

At the start of our observing period this fascinating planet is an evening object, close to and to the lower right of Mars, but it will be extremely low in the west after sunset, setting only 20 minutes after it. From then on Mercury rapidly drops out of view, falling down towards the Sun until it's lost in its glare.

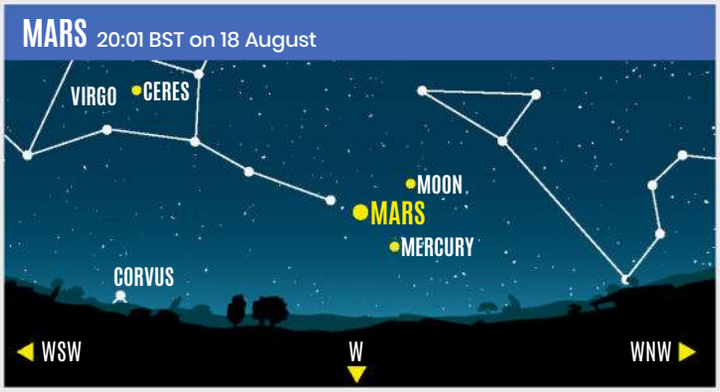
VENUS 06:00 BST on 23 August



Constellation: Cancer **Magnitude:** -4.2 **AM/PM:** AM

At the start of our observing period Venus will be too close to the Sun to be seen, but by late August will be a 'morning star', rising half an hour before the Sun and shining low in the east as the sky brightens. Its magnitude of -4.2 means you should be able to see it as a spark in the morning twilight.

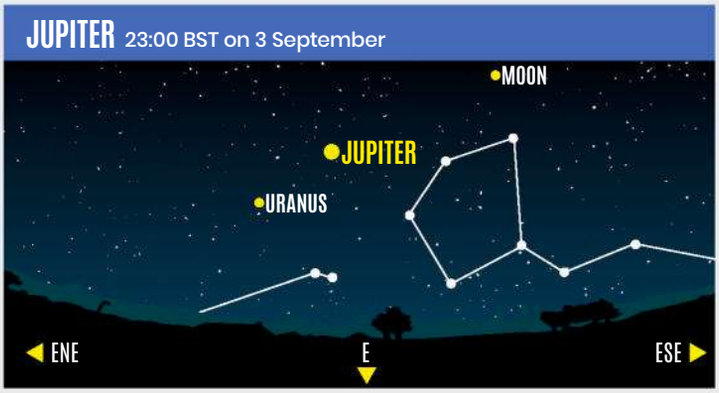
MARS 20:01 BST on 18 August



Constellation: Leo **Magnitude:** +1.8 **AM/PM:** PM

The Red Planet will be visible as an orange-hued star low in the west after sunset in early August, shining not far to the upper left of Mercury in the evening twilight. However, its meagre magnitude of +1.8 will mean you'll probably need a binocular to pick it out in the bright sky.

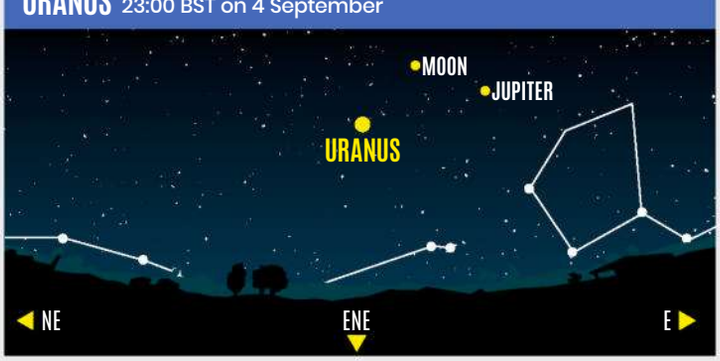
JUPITER 23:00 BST on 3 September



Constellation: Aries **Magnitude:** -2.5 **AM/PM:** AM

At the start of August Jupiter will be an evening object, rising in the east some two hours after the Sun has set. It will then be visible all through the night, looking like a bright blue-white star in the sky. Look for the last quarter Moon shining just to the right of Jupiter late in the evening on 8 August, and to the left of it the next evening.

URANUS 23:00 BST on 4 September



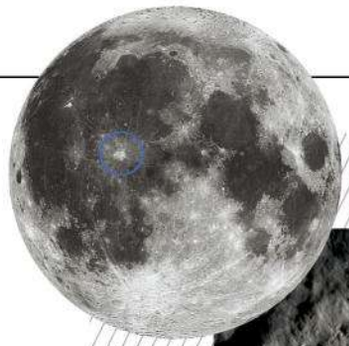
Constellation: Aries **Magnitude:** +5.8 **AM/PM:** PM

As August begins Uranus is an evening object, a pinprick green star just nine degrees to the east of bright Jupiter. Unfortunately, there are lots of stars around Uranus with the same magnitude, so if you need a little extra help identifying the planet, look for a green-hued star roughly halfway between Jupiter and the Pleiades.

NEPTUNE 21:00 BST on 4 September

Constellation: Pisces **Magnitude:** +7.9 **AM/PM:** PM

A magnitude of +7.9 means it's so faint that a good binocular or a small telescope is needed. During the month ahead this ice giant will be found 22 degrees or so over to the east of Saturn. If you can manage to find it you'll see its distinctive blue-green hue, but you'll need to crank up the magnification a lot to see its disc.



MOON TOUR

COPERNICUS

Get up close to the 'Monarch of the Moon'

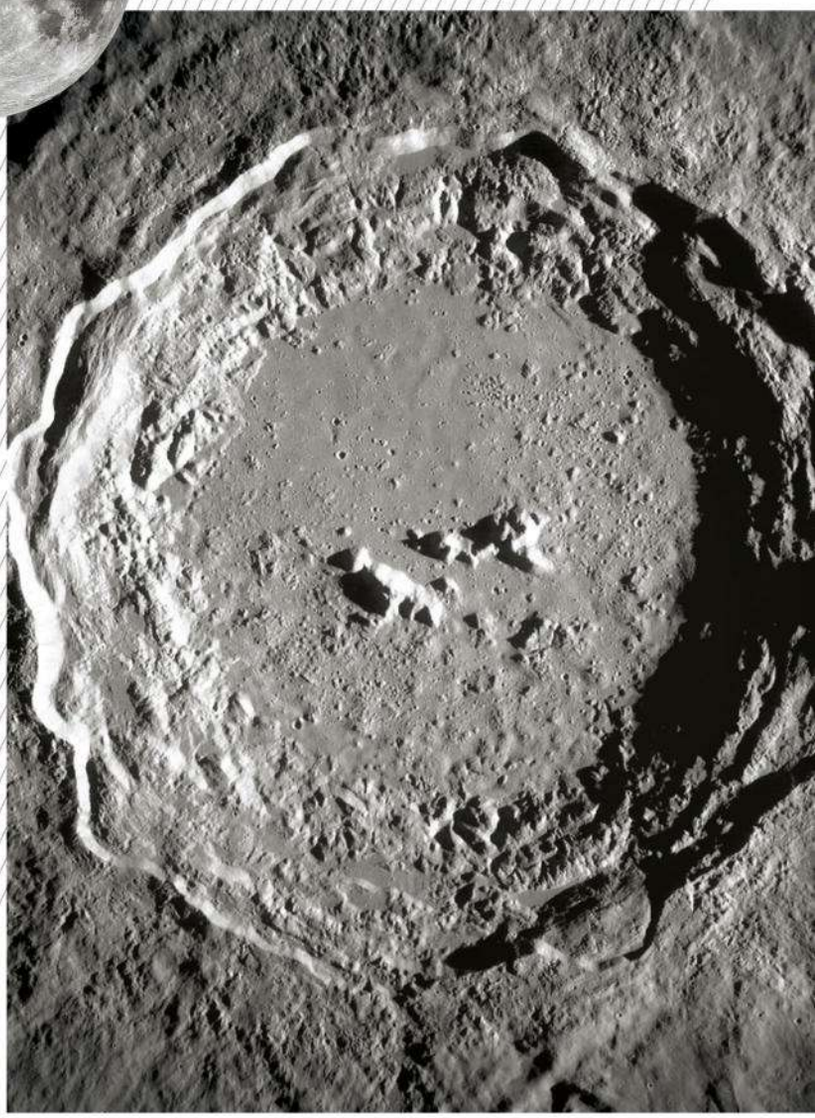
If you've ever seen a documentary about the Moon, you'll have seen someone enthusiastically hurling a stone into a tray full of flour to demonstrate how impact craters are formed. Of all the hundreds of thousands of craters on the Moon, one looks exactly like the feature these dramatic demonstrations produce – a deep, sharp-edged pit surrounded by rays of debris. Copernicus looks exactly like a lunar crater should: a great hole in the Moon with a dark, shadowed floor; a high, sky-scratching rim and lots of bright rays of dust and pulverised rock splashing away from it. Its nickname, the Monarch of the Moon, is entirely justified – no other crater comes close to it for sheer 'wow' factor when seen through a telescope eyepiece. That's why lunar observers go back to it again and again and again, staring down into it every chance they get.

Copernicus is young in lunar terms. It was formed between 800 million and 1 billion years ago when the most advanced forms of life on Earth were essentially clumps of scum floating about in the oceans. One day the Moon was struck by a large asteroid, and the enormous explosion caused by the impact blasted a huge hole out of the area of the Moon we know as Oceanus Procellarum, or the Ocean of Storms. The gaping pit left behind was almost four kilometres (2.5 miles) deep and more than 93 kilometres (58 miles) wide. But the impact didn't just blast out a hole; it sent enormous amounts of debris spraying out across the lunar landscape. Some of it fell back down to the Moon, leaving bright rays of ejecta on the surface. The longest of these debris rays stretches for over 800 kilometres (50 miles) and can even be seen with the naked eye when the Moon is full, looking like white chalk lines drawn on the Moon's darker face.

Seen through a telescope, or from an orbiting probe, Copernicus is roughly hexagonal in shape. Its walls are steep and terraced on all sides, giving the strong impression of a flight of stairs descending to its floor. High magnification shows where a wide shelf of rock has dropped down on the western side, and hints at landslides in several places. The northern part of the crater's floor is quite flat, but the southern half is hummocky and hilly, pocked here and there with many smaller, much younger craterlets. In the centre of the crater a trio of mountains protrude from the lava plain. The tallest one, close to the western wall, has a peak which rises above the crater's floor.

In November 1969 the Apollo 12 Lunar Module Intrepid set down at a landing site around 350 kilometres (217 miles) south of the huge crater. So precise was Intrepid's landing that its crew, Pete Conrad and Alan Bean, were able to walk to the Surveyor 3 probe. After carefully removing pieces of the probe to be studied back on Earth, they collected samples of rock, some of which might have showered from the sky after the formation of Copernicus almost a billion years earlier.

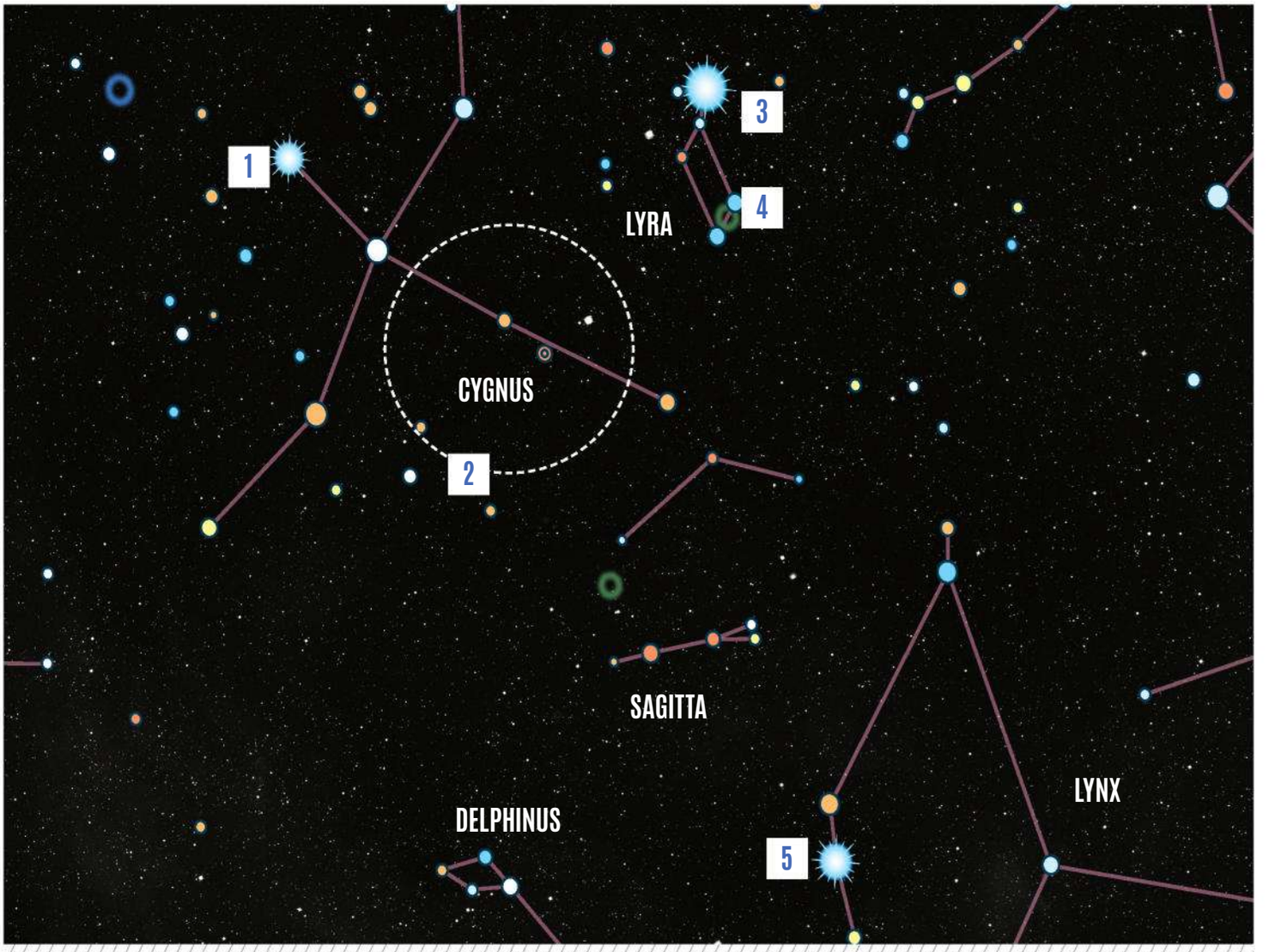
How and when can you see this celebrity crater on the Moon during the month ahead? At the start of our observing period Copernicus is hidden from view, deep in lunar night. You'll have to wait until the evening of 29 July for your first sighting of it as it emerges from the darkness with the approach of the terminator, the line between lunar night and day. As dawn breaks over Copernicus' eastern horizon it will come fully into view until 10 August, where it will be available for your attention with a binocular or telescope. When the Moon is full on 1 August, the crater's system of rays will appear at their most dramatic and obvious.



TOP TIP!

Copernicus looks most impressive just after first quarter or just after last quarter Moon.

© NASA



NAKED EYE AND BINOCULAR TARGETS

See a cloud of stars and shells of gas produced by faraway dying suns in the summer sky

1 Deneb (Alpha Cygni)

Deneb is one of the three stars of the famous Summer Triangle. Its name means 'tail of the Swan', and it also stands at the head of the well-known asterism the Northern Cross. At magnitude +1.3 it's the 19th-brightest star in the sky. It's 1,400 light years from the Sun and around 200,000 times more luminous.

2 The Cygnus X star complex

Running down the right side of the Northern Cross, the Cygnus star cloud looks like a long, misty patch of light to the naked eye. Look at it through binoculars and you'll see it's made up of countless millions of glittering, faint stars, all thousands of light years from Earth.

3 Vega (Alpha Lyrae)

Icy blue-white Vega is the fifth-brightest star in the sky now, but in 290,000 years it will be the brightest star in the heavens. Only 25 light years from Earth – a next-door neighbour in cosmic terms – this Summer Triangle star spins so quickly that it's flattened at its poles, like Saturn.

4 The Ring Nebula (Messier 57)

Messier 57 is the remains of a dead star that puffed out its outer layers many centuries ago. It's called a planetary nebula because its ring looks like a planet's disc through a telescope. You'll need binoculars to see it as a tiny blue-green spot.

5 Altair (Alpha Aquilae)

Only 16.8 light years from Earth, Summer Triangle star Altair is the 13th-brightest star in the sky. Spinning at more than 210 kilometres (130 miles) per second, it takes ten hours to rotate once, which flattens it into an oval shape.

1 The Veil Nebula as it appears in ultraviolet

DEEP SKY CHALLENGE

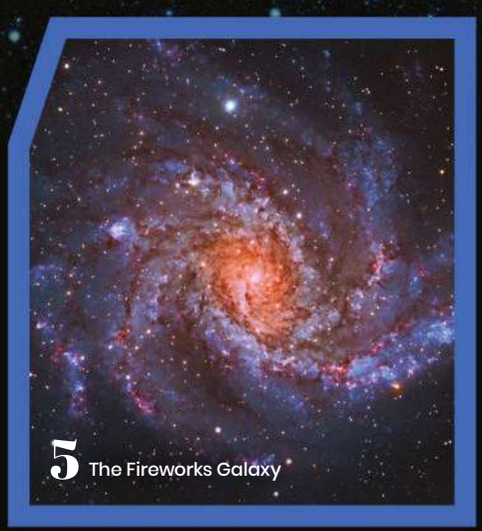
DIVING DEEP INTO THE SUMMER SKY

The ghostly remains of dead stars, glittering ancient star clusters and a spectacular galaxy far, far away await

Astronomy is, very generally speaking, the study of the stars and everything to do with them – how they are born, live and die; how they work; the objects that go around them and much, much more. The sky throughout August and September offers the naked-eye observer some of the most beautiful stars in the sky, and the mottled band of the Milky Way too, itself made out of countless billions of stars.

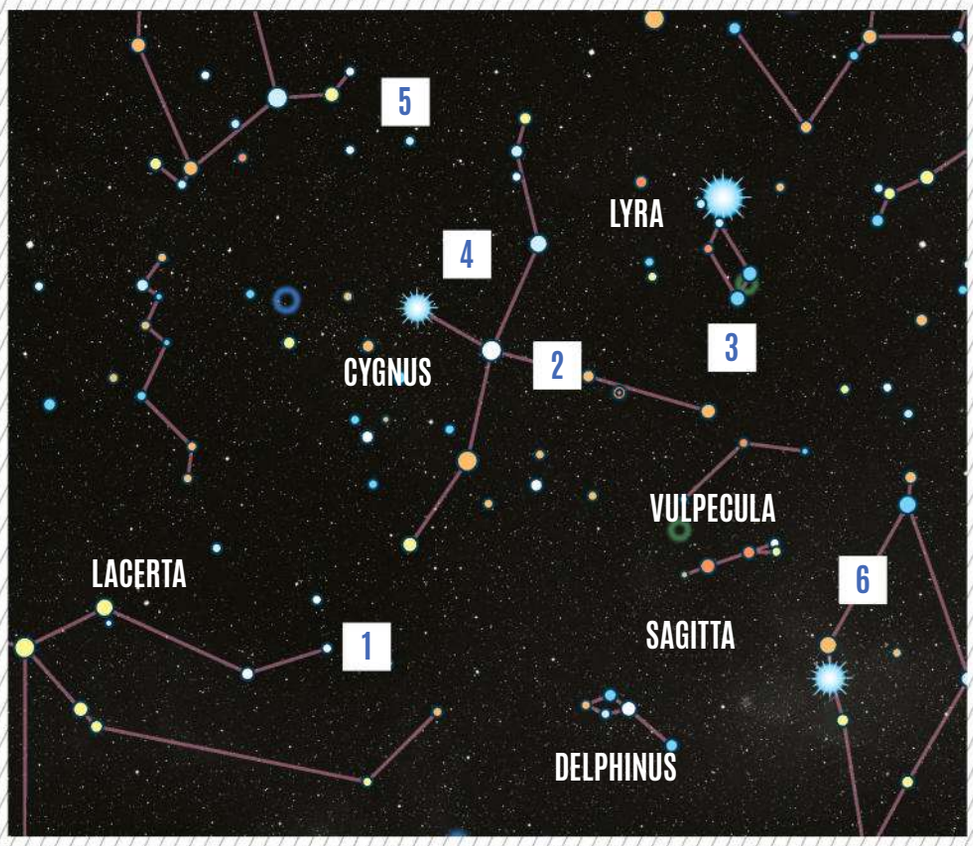
But beyond the stars, through their misty veil, lie objects that are as fascinating as they are faint, as beautiful as they are subtle. Four of our six challenging deep-sky objects this month are nebulae, one is a distant glittering star cluster and the sixth is another galaxy altogether, an elegant Catherine wheel of stars far beyond the boundary of our own Milky Way. All these objects are going to be a challenge for you if you live somewhere that isn't blessed with a dark sky, and a couple require a large telescope to see them, but they are all worth looking for.

The ghostly, curled wisps of the Veil Nebula are all that remains of a once-mighty star that blew up millennia ago. NGC 6946 is a tightly wound spiral galaxy positively popping and fizzing with star formation. Messier 56 is one of the faintest objects in Messier's famous catalogue – an enormous ball of perhaps a million stars, reduced in a telescope eyepiece to a tiny, smoky ball by its incredible distance. All you need now is a clear night!



5 The Fireworks Galaxy

"The ghostly remains of a star that blew up around 8,000 years ago"



1 THE VEIL NEBULA

The ghostly remains of a star that blew up around 8,000 years ago, the Veil Nebula is fifth magnitude, but is so large and diffuse that you'll need a telescope and a dark sky to see its faint, misty arcs.

2 THE CRESCENT NEBULA (NGC 6888)

This magnitude +7.4 emission nebula has a distinctive crescent shape in a low-power telescope's eyepiece. Around 5,000 light years away, the nebula is best seen using averted vision.

3 MESSIER 56

One of the faintest globular clusters in Messier's catalogue, magnitude +8.3 Messier 56 can be resolved almost to its centre through a telescope's high-power eyepiece.

4 THE BLINKING PLANETARY (NGC 6826)

This magnitude +8.9 planetary nebula looks like a small blue-green oval in a large telescope. Looking at and then away from its central star makes the nebula appear to blink on and off.

5 THE FIREWORKS GALAXY (NGC 6946)

The curved arms of this beautiful face-on spiral galaxy are best seen through the high-power eyepiece of a large telescope. The galaxy is ablaze with colourful areas of star formation.

6 NGC 6803

At magnitude +11.5, this planetary nebula is so faint you'll need a large telescope under a very dark sky to see its tiny pale-blue disc. It's more than 6,000 light years away from Earth.

3 Messier 56

© NASA \ ESA; JPL-Caltech; Göran Nilsson & The Liverpool Telescope

NORTHERN HEMISPHERE

Autumn brings some astronomical favourites into view

Circumpolar Cassiopeia (the Queen) and Cepheus (the King) lie in the dusty path of the Milky Way, offering not just a rich starfield, but impressive deep-sky objects. The Owl Cluster (NGC 457) is easy to pick out with decent binoculars, with bright double star Phi Cassiopeiae forming its eyes. Double star Alpha Cassiopeiae can easily be split into a stellar pair: a bright, yellow primary and faint, blue secondary. Use Pegasus, Aquarius and Pisces and you'll be able to locate Cetus (the Sea Monster), which contains the remarkable variable star Mira, or Omicron Ceti, as well as a wide selection of galaxies.

Melotte 15

Perseus, Andromeda and Pegasus above the Columbia Icefield, Canada

Messier 15

Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

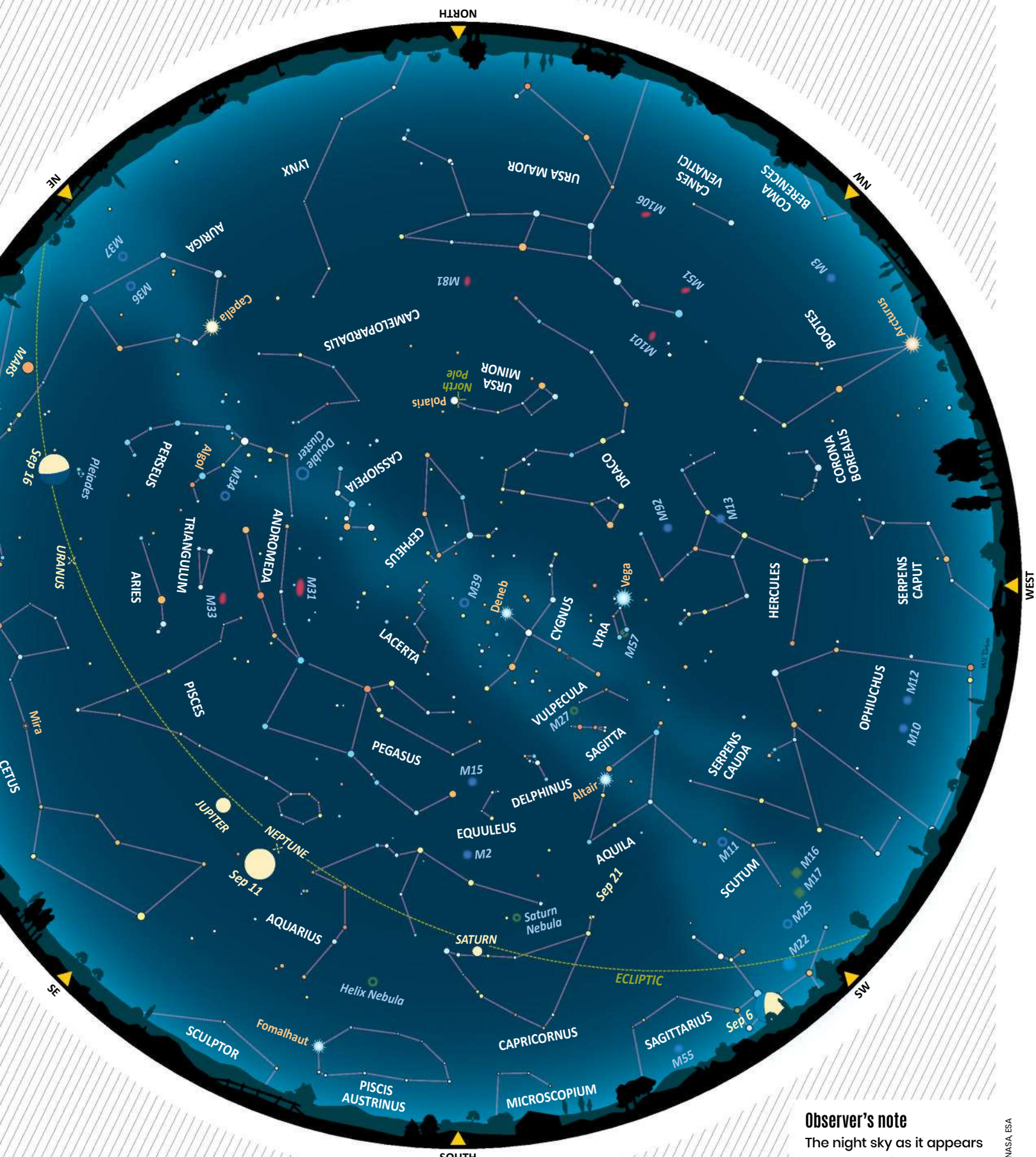
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O-B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note

The night sky as it appears on 17 September 2023 at approximately 22:00 (BST)

© Getty / NASA ESA

REVIEW

CELESTRON STARSENSE EXPLORER DX 102AZ

Innovative technology provides the simplest and quickest solution yet to finding objects to observe, and this instrument will be very popular with beginners

Reviewed by Robin Scagell

DETAILS

Cost: £379.95 / $469.95
From: Celestron
Aperture: 4"
Focal length: 25"

The night sky is full of interesting objects that even a small telescope can show in detail, but actually finding them has always been a problem for beginners. The advent of computerised star catalogues loaded into telescope handsets made it possible to align a telescope on the sky by pointing it at just three bright stars. Once done, the handset could direct the telescope to any other object in its database, but it needed position encoders on its axes. And all this requires some user input – the date and time, the location and choosing the stars.

Then along came 'plate solving' – the software to identify a field of view of stars in a photograph – and the great computing power, position sensing and imaging capabilities of a modern smartphone. Celestron's magic solution has been to link these to a telescope, doing away with the need for the costly handset, the user input and the encoders. Its StarSense technology links a smartphone to a telescope in a simple but robust fashion.

There are four instruments in the Celestron StarSense Explorer range: an 80mm refractor, a 114mm reflector, the 102mm refractor under test and a 130mm reflector. All of these instruments are standard members of the Celestron range and are available in other mounting packages. In this range, the 80mm refractor and 114mm reflector are supplied on lighter weight mountings, while the 102mm refractor and 130mm reflector have the same heavier mounting. Because these mountings use a standard Vixen-type or CG-5 dovetail attachment, you can attach any other instrument that uses the same dovetail, taking into account the load capacity of the mounting.

The alt-azimuth mounting means that you can move the instrument around two

The telescope assembly is packaged with an alt-azimuth mount and accessories

BEST FOR...

- MEDIUM BUDGETS
- BEGINNERS
- LUNAR OBSERVING
- BRIGHT DEEP-SKY TARGETS
- PLANETARY OBSERVING

The telescope comes equipped with an erect-image star diagonal

A smartphone holder is a staple of the StarSense series

axes – up and down (altitude) and from side to side (azimuth). This is the simplest form of mounting and is particularly suitable for a beginner's instrument. The alternative equatorial mounting, which has one of its axes tilted at the same angle as your latitude, not only confuses many beginners but has the drawback that it involves an overhanging load usually balanced with a counterweight, reducing portability.

The mounting of the Celestron StarSense Explorer DX 102AZ is completely manual, with flexible rods to allow what are called slow motions, providing a finer control over the movement than simply pulling and pushing the instrument. The extra ingredient over a standard manual mounting is the attachment for a smartphone, which is directly fixed to the central assembly. This is not to be confused with smartphone attachments that simply enable you to take photos of bright objects through the eyepiece, as found on some other beginners' instruments.

This is an achromatic refractor with a 102mm doublet lens composed of two different types of glass. It has a focal ratio of f/6.5, which means it has a comparatively short tube for its diameter – a situation that provides a wide field of view and bright image with a fairly compact instrument. The word 'achromatic' implies a freedom from the false colour that bedevilled refractors in the very early days of telescopes, but this is a comparative term. Like other achromatic refractors, the instrument still has some false colour, which shows as coloured fringes around the edges of objects, particularly at high magnifications, and the short tube results in inherently more false colour than with a longer focal ratio achromatic instrument. To completely overcome false colour you need a considerably more expensive apochromatic refractor, or a reflector. However, refractors are traditionally more robust than reflectors, so there's no ideal instrument to suit everyone.

The package comes with two eyepieces, giving two useful magnifications of 26x and 66x, and what is termed an erect-image diagonal. A star diagonal is standard with astronomical refractors and reflects the beam from the focuser through 90 degrees to allow a much easier observing position than crouching on the ground looking up through the tube, but usually it has the drawback of reversing the image, as in an ordinary mirror. The diagonal provided by Celestron uses a roof prism rather than a simple mirror, giving a non-reversed image so you can use the instrument by day as well as by night. It also avoids the confusion of viewing the Moon's features or star fields back to front. Finally, there's a standard red-dot finder to help in pointing the telescope at objects. This is necessary when aligning the telescope, as you need to point it at a recognisable object at the start of observing.

"StarSense technology links a smartphone to a telescope in a simple but robust fashion"

The instrument comes in just two main parts – the tripod and the tube assembly – so it seems straightforward. The accessory tray that sits in the middle of the tripod legs, however, needs to be attached by fiddly little thumb screws that are already in place, but the wrong way round in their holes. Why use such a time-consuming means of attachment? This is poor design, as these screws will quickly get lost. A simple slot-and-turn system would be much less aggravating, unless you intend to use the instrument solely as a piece of furniture permanently set up in the corner of the room – or do without the tray altogether.

The telescope attaches to the mount using a standard dovetail, but as it came out of the box the clamp assembly was twisted through 180 degrees, with the locking screw at the bottom. The instructions tell you to turn it, but this is easier said than done. It seems immovable, and many beginners will wonder if they are meant to be forcing this at all. In fact, you do need to apply a lot of force to twist it. Confusingly, the instructions then refer to the knob at the bottom of the clamp.

One problem we faced was that the instrument was difficult to slew

Once set up, you need to align the red-dot finder with the main instrument by day. Unfortunately, the adjustment range on the device supplied did not allow it to be aligned accurately, and for the test we used another one that we already had. The final step is to remove the cap from the mirror on the StarSense dock – again pulling it off with some effort – and fitting your smartphone into the spring-loaded slider. Bear in mind that not all smartphones will work, and check your model against a list on the Celestron website before taking the plunge. It must have a camera sensitive enough to image the brighter stars using a night setting. We're pleased to report that loading and using the software on a Moto G8 was easy and quite intuitive. This is fortunate, as the Quick Start manual ends at this point. All the following stages are accomplished using the StarSense app, which you need to unlock using a code supplied with your instrument, working with up to five devices.

The camera views the sky through a mirror, enabling you to view the phone's screen at a convenient angle. The StarSense app displays the camera's view of the night sky using a time exposure if necessary, so it may take some seconds to appear or refresh. The method of alignment is to aim the telescope at a chosen object – which is where the red-dot finder comes in handy – and then move the red crosswires on the app to the same object shown on the phone view. You can zoom in for better precision.

Now you are in business and you can choose from a list of objects observable with this instrument at the time, graded according to whether they can be seen from the city or from a dark sky. Once chosen, you'll see a set or arrows on the screen that tell you which way to move the telescope to get to that object. Within seconds you're on target and the crosswires turn green. Moving from one object to another takes just seconds – the quickest finding system we've seen.

Some drawbacks do become evident. The finding system isn't always spot on, so you need to be prepared to search for objects around the edge of the field of view. The clutch that holds the telescope in altitude, on the test model at least, is fierce, so to move it you need to grasp the tripod firmly with one hand and wrench the tube up or down with the other as per the instructions. The altitude slow motion is equally stiff to turn, while the azimuth control had an annoying backlash.

One major source of problems was the mirror, which is crucial to finding objects. The software constantly checks the alignment of the instrument and complains if it can't see the sky, so snapping on the cover in between observations isn't easy or ideal. The mirror can become dewed up within minutes on some nights – often the clearest. Unlike household mirrors, its reflective coating is on the front surface rather than the back, so regularly wiping it clear could result in damage to the coating. Unwary users are likely to try polishing it with glass cleaner or even abrasive solutions.

Optically, the telescope is well up to standard for a short-focus achromatic refractor, and is well suited to deep-sky observing. The eyepieces supplied, although in lightweight plastic barrels, are of good optical quality. Boosting the magnification using a Celestron 2x Barlow lens revealed false colour in lunar and planetary images, so this is not an ideal high-power or planetary instrument. The erect-image diagonal, which is necessary to allow the instrument to focus, introduces very little distortion, only marginally noticeable on a star image using a magnification of 130x.

Once you're accustomed to the instrument, finding objects is extremely quick and fun. The optical quality is good for a telescope of this type, but for planetary observing a different instrument would be preferable, such as the 130mm reflector in the same range. The clunky movement and delicate mirror could limit the usefulness of the instrument for more detailed observations, but the system certainly does get you observing within just a few minutes, unlike more advanced instruments, thus overcoming one of the greatest hurdles that beginners face.

The pricing of this instrument isn't significantly less than that of the Celestron NexStar 102 SLT – the same instrument on a fully motorised mount, which has the great advantage of tracking objects for you. Whether you buy this model or opt for the full Go-To version, or indeed the NexStar 130 SLT reflector, is a decision that you will have to make depending on your observing interests.

FOR

- ⊕ Very easy and quick to find objects
- ⊕ Almost intuitive push-to method of homing in
- ⊕ Excellent on-screen information and listing of objects to view in a night's observing
- ⊕ Sensible choice of eyepieces provided and good optical quality for deep-sky observing

AGAINST

- ⊖ Alignment procedure depends on a mirror
- ⊖ Dews up quickly
- ⊖ Slow motions are somewhat clumsy
- ⊖ Instrument is stiff to move

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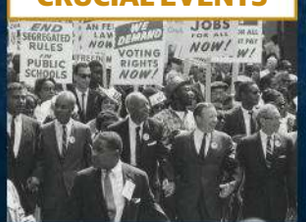		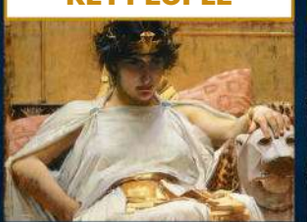		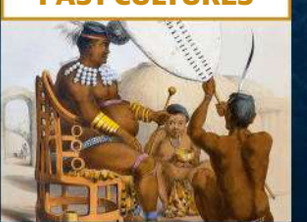

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IN THE SHOPS: STAR PROJECTORS

Our round-up of the best star projectors on the market right now

Sega Toys Homestar Flux

Cost: £169 / $229
From: Sega Toys

1 One of the sleekest-looking and most powerful star projectors around, the Homestar Flux, though compact, comes with a high price. More of a home planetarium than a simple star projector, we found that the Flux's multilevel glass lenses produce realistic-looking night skies from the comfort of your own home – it's also bright enough for rooms that aren't totally dark. After adjusting the focus to suit your projection surface, you'll see 60,000 stars – many more than its competitors. This globe-shaped product excels with the sheer number of distinct stars it projects, and it has some tempting science-based upgrade options. The Flux comes with two discs: the Northern Hemisphere and the Northern Hemisphere constellations. One shows a starry sky with 60,000 stars, while the second contains constellation labels to aid with learning. There are a further 17 Sega-branded discs available, though these are to be purchased separately.

Smithsonian Optics Room Planetarium and Dual Projector Science Kit

Cost: £115 / $80
From: Smithsonian Store

2 Shipping with an adjustable desktop stand, you can aim the projector wherever you like and see stars across the ceiling and walls. With the default planetarium slide you can make the stars rotate and move, using them either as the sole image or as a background to other images that come from three other slides in the box: 24 simple still images of objects ranging from the Sun, Earth, Moon, asteroids and planets; the International Space Station; Space Shuttle; an astronaut on a spacewalk and deep-sky sights such as galaxies and nebulae. It also includes an educational poster. It's something intended for a child rather than an adult. It shows only the stars of the Northern Hemisphere and lacks labels and constellation guidelines, so whether or not it's possible to learn anything from its projections is questionable.

National Geographic Astro Planetarium

Cost: £99.99 (approx. $128.50)
From: Bresser

3 The National Geographic Astro Planetarium is a high-quality indoor planetarium that accurately represents the night sky and comes with plenty of extras. Two projection discs are included: one shows 8,000 stars and the other overlays guidelines for the major constellations. What you see is true to the time and day you set it. The result is a bright and sharp projection on the ceiling. However, stars at the edge of the projection can seem blurry. An optional falling star mode projects a flashing 'meteor' every 40 seconds, though always in the same place. In the box are four educational posters, three AA batteries and a 3.5mm jack cable, the latter of which is to hook up a smartphone or other audio device to play through this star projector's small mono speaker. It also acts as an FM radio if you want to listen to music or soothing sounds while you stargaze indoors.

"This laser-powered galaxy projector takes viewers on a journey through multicoloured clouds"

Blisslights Sky Lite 2.0

Cost: £49.99 / $49.99
From: Blisslights

4 Imagine being immersed within a star cluster or drifting through a nebula. If you want scientific accuracy look elsewhere, for what you get with the Sky Lite 2.0 is a mesmerising ambient experience that makes up for in creativity what it lacks in scientific rigour. This laser-powered galaxy projector takes viewers on a journey through multicoloured clouds. We found it very easy to set up and liked its easy operation. It can be set to project at three different angles, including upwards onto a ceiling. It uses an LED and direct laser diode, which together create motion-filled RGB projections. Portability is further helped by a USB power cable, which means the Sky Lite 2.0 can be powered by a computer or from a portable battery. This latest 2.0 version also includes the BlissLights smartphone app, which lets the user connect via Bluetooth and choose from seven built-in effects modes, customise the projector's intensity, the brightness of the laser and the rotation speed.

Bresser Junior Astro Planetarium

Cost: £87.99 (approx. $113.05)
From: Bresser

5 Though not as vibrant as Bresser's National Geographic Astro Planetarium, the Bresser Junior Astro Planetarium is an almost identical product. This incarnation has the same essential specifications and projections and works in the same way, but there are some notable differences. The same Astro Planetarium multimedia discs are included – one featuring a starry night sky and the other overlays of constellations – and it's all entirely accurate for the time and day you're using it. You can rotate the image through 360 degrees using its built-in motors and it's easy to adjust the image using a focusing wheel around the lens. It can be set to automatically shut down after 30, 60 or 120 minutes, which is useful if it's intended for a child's bedroom and they want to fall asleep under the stars. It's also got a falling star mode, which can be activated to project a 'meteor' every 40 seconds.

Omegon Star Theatre Pro Planetarium

Cost: £87 / $99
From: Omegon

6 Here's a star projector that's a more serious astronomical device than some, but only just. Shipping on a small tripod desktop stand, the Omegon is powered by a USB cable, which means it can be attached to any portable battery source – helpful if you want to place it in the centre of a room. The adjustable projection distance is handy, but although it illuminates the ceiling with a realistic night sky of 10,000 stars, it lacks brightness, ultimate sharpness and stellar accuracy. For example, you can't adjust it to be time and date specific, hence you're only getting a random starry night sky that lacks context, labels or constellation guides. It's tricky to find anything you might recognise, though it does include the arc of the Milky Way. It's suitable for anyone after a decorative night sky projection, but not necessarily effective as a learning device.

TYCHO BRAHE

The peculiar life of the last great naked-eye astronomer revealed

Brahe was born on 14 December 1546 in Scania, Denmark (now Sweden). At the age of 12 Brahe studied law at the University of Copenhagen as per his uncle's wishes, but he quickly developed a love for astronomy. He soon realised becoming a great astronomer meant spending many nights poring over observational data and would often spend his evenings doing just that. His uncle wanted him in law, so when Brahe was sent on a study tour of Europe at the beginning of 1562, he was limited to performing astronomy in his spare time.

Part of his nose was prosthetic, revealed in 2012 to have been made out of brass. Brahe had received this disfiguring wound from another Danish nobleman, Manderup Parsberg, on 29 December 1566, after the two disagreed over a mathematical formula. A year prior to this injury, in 1565 Brahe's uncle had died of pneumonia, and two years later Brahe fully devoted himself to astronomy. With the help of his maternal uncle, Steen Bille, he built an observatory and alchemical laboratory at Herrevad Abbey in former Denmark.

Brahe is often regarded as the last great naked-eye astronomer, as it was not long after his time that Galileo invented the telescope. It was from his observatory that he began making notable discoveries, including one on 11 November 1572: a very bright star in the constellation of Cassiopeia, now known to be a supernova. His measurements revealed that it must have been very far away – farther than the Moon and the planets – challenging the commonly accepted theory that objects beyond lunar orbit were in a state of antiquity.

Over the next two decades he made more and more significant discoveries from various observatories. He was the first to realise comets were farther away than the Moon, rather than within the atmosphere, as had previously been believed. He also performed some of the most precise observations of the night sky at the time before the arrival of the telescope. One of his biggest contributions to astronomy, however, actually came about after his mysterious death in 1601. Brahe had been hugely protective of his work throughout his life, but with his passing, his assistant – famed astronomer Johannes Kepler – was able to use Brahe's detailed observations of Mars to formulate his groundbreaking laws of planetary motion.

Brahe's life was certainly an eventful one. Alongside personal drama he made some monumental discoveries and observations in the field of astronomy, and today he is still regarded as one of the most important astronomers of all time. Perhaps he would find it fitting that one of the Moon's most notable craters is named in his honour.

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Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Editor **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Production Editor **Nikole Robinson**
Senior Art Editor **Duncan Crook**

Contributors
Stuart Atkinson, Charles Q. Choi, David Crookes, Matija Ćuk, Shawn Dahl, Daisy Dobrijevic, Curtis Fermor-Dunman, Andreea Font, Robert Lea, John Loeffler, Tariq Malik, Pawel Pietrukowicz, Danny Price, Giles Sparrow, Colin Stuart, Paul Sutter, Joanna Thompson, Neil deGrasse Tyson, Mike Wall, Ian Whittaker, Steve Williams; James Wurster

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Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Advertising Sales Director **Lara Jaggon**
lara.jaggon@futurenet.com
07515 961 911
Account Manager **Hayley Brailey-Woolfson**
hayley.brailleywoolfson@futurenet.com
01643 678 054

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Production
Head of Production **Mark Constance**
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SVP Lifestyle, Knowledge and News **Sophie Wybrew-Bond**
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Head of Art & Design **Greg Whitaker**

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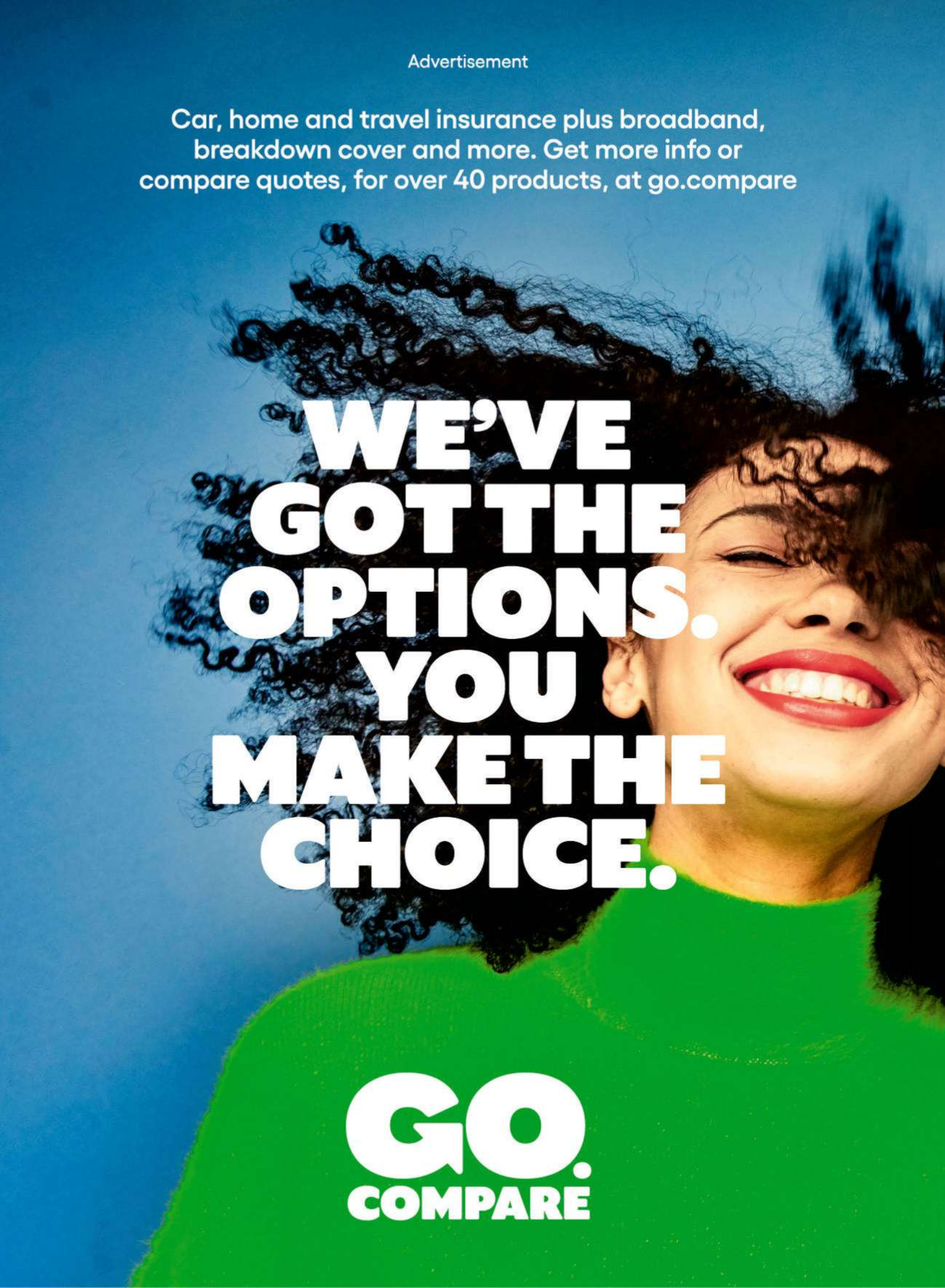

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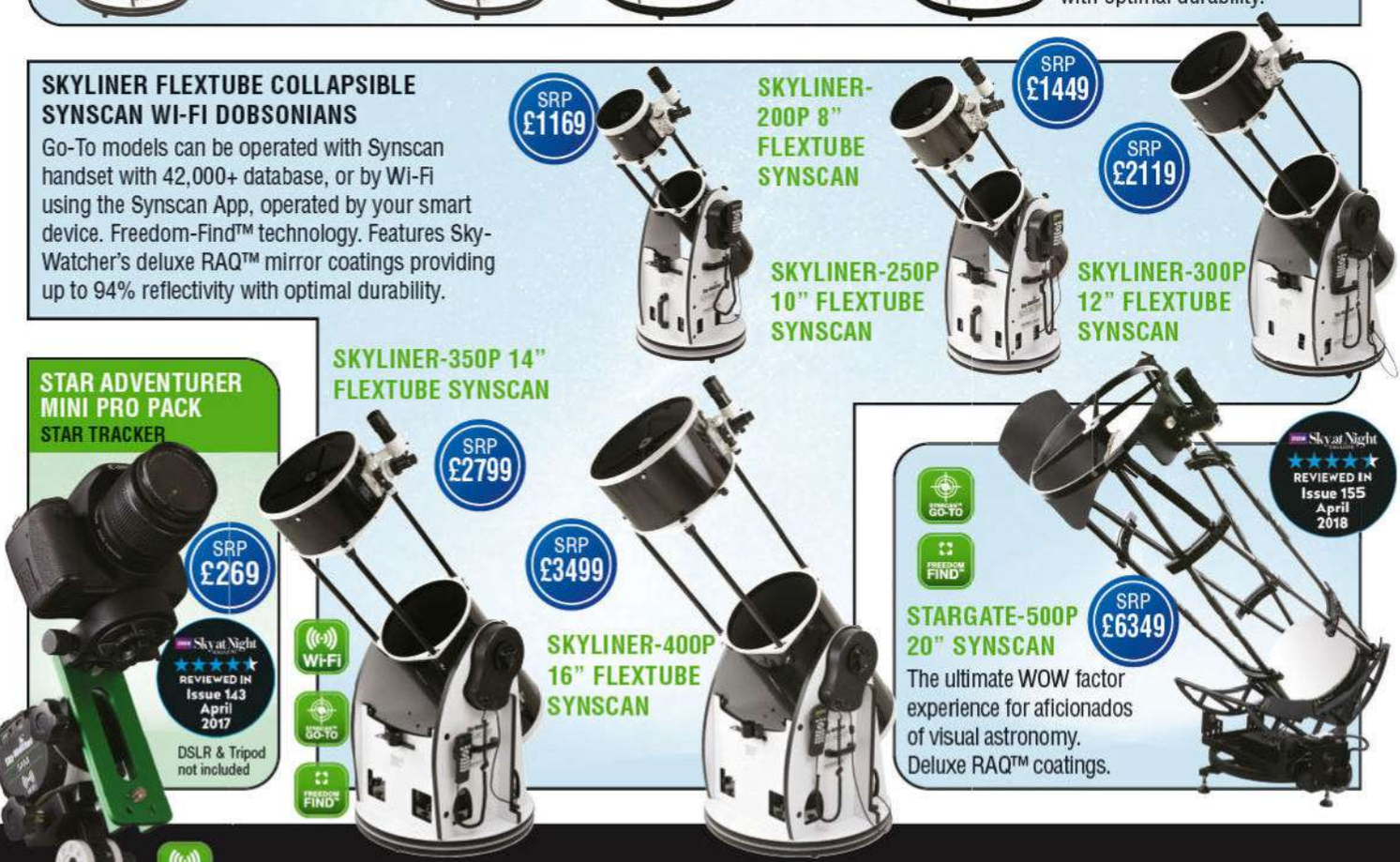

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